# Spatial Access to Comprehensive Emergency Obstetric and Neonatal Care and its Relationship to Mortality at the Regional Level in Sub-Saharan Africa and at a National Level in Kenya

## Thesis




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# Spatial access to comprehensive emergency obstetric and neonatal care and its relationship to mortality at the regional level in sub-Saharan Africa and at a national level in Kenya

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**PhD Thesis**

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# DEDICATION

This thesis is dedicated to my family, the Ouma's for your never ending support.

To my nephew Jeremy who was born with VLBW and had to spend 2 months in a NICU, anything is possible

# ABSTRACT

**Background:** Geographic access to hospitals is a key determinant of health outcomes and is critical in achieving Universal Health Coverage. Hospitals are the entry points for provision of comprehensive emergency obstetric and neonatal care. In sub-Saharan Africa where maternal and newborn deaths are disproportionately higher than anywhere else, defining those who are marginalised from these services is critical in in efforts to reduce these deaths. This thesis aimed to define geographic access to Comprehensive Emergency Obstetric and Neonatal Care (CEmONC) at a regional level in sub-Saharan Africa (SSA) and at a national level in Kenya and relate these access quotients to maternal and neonatal mortality.

**Methods:** A spatial database of public hospitals covering 48 countries and islands in SSA, was assembled using a range of sources from both national and international organizations. Based on a review of minimum essential services at first level referral hospitals, the assembled hospitals were assumed to provide CEmONC. These were then used in a cost distance algorithm that adjusted for proximity to roads, to estimate the proportion of women of childbearing age (WoCBA) living within two hours of the nearest public hospital. The accessibility algorithm accounted for complexity in transportation derived from a review of transport speeds to hospitals and different modes of transportation. The derived access quotients were then used to define the relationship between access to hospitals and modelled estimates of both neonatal mortality rate per 1,000 livebirths (NMR) and maternal mortality rate per 100,000 livebirths (MMR) while controlling for other confounding factors. Confounders chosen were physician workforce density, poverty, adolescent-specific fertility, risk of catastrophic expenditure for surgery, the proportion of urban population and fragility. A country case study was then chosen to undertake a more exhaustive analysis of geographic accessibility and its impact on the two outcomes. Using Kenya as an example, service availability assessment was carried out using different datasets to map hospitals that provide services for caesarean section (CS) and very low

birthweight (VLBW) newborns. These were chosen as tracer services for provision of CEmONC. A cost distance algorithm that adjusted for the proximity to roads, road condition, land use, elevation and rainfall patterns was developed to define geographic accessibility to both services in Kenya. Lastly, an assessment of the relationship between access to CS and VLBW hospitals in Kenya with maternal and neonatal mortality respectively was undertaken. Relationships were evaluated using maternal mortality data from the 2009 census while the Equitable Strategies Save Lives Tool (EQUIST) tool was used to generate both maternal and neonatal mortality.

**Results:** 4908 public hospitals were mapped for the 48 countries. Accessibility results showed that 704 million (71%) people and 164 million (72%) WoCBA were living within 2 hours of the nearest public hospital across, which varied from 22.8 in South Sudan to 97.4 in Zanzibar. Only seventeen countries had more than 80% of their respective populations within 2 hours of a public hospital. In the continental level regression model, a 1% increase in WoCBA within 2 hours was associated with a reduction of MMR by -2.75 (p=0.039) but was not significantly associated with a reduction in NMR, with a coefficient of -0.01 (p=0.717). In the Kenya accessibility analysis, 228 and 293 hospitals were determined to provide VLBW and CS services respectively, out of a total 431 possible hospitals. Overall, 82% and 80% of the births needing CS and VLBW services respectively occurred within 2 hours of the nearest hospital. Access to CS and VLBW services was heterogenous and varied from 25.7 and 21.8% in Turkana to 100% in Nairobi and Vihiga. Regression models that accounted for confounders showed a 1% increase in access to CS hospitals was associated with are reduction of MMR by -11.92 (p=0.018) using census MMR and -3.81 (p=0.000) using the EQUIST MMR. Finally, using NMR output from the EQUIST model, increasing access to VLBW hospitals was associated with a reduction of NMR by -0.24 (p=0.050). Thus, using the census outcome as an example suggests that MMR in high burden counties of Mandera, Marsabit, Turkana and Wajir would reduce by 457, 452, 647 and 540 per 100,000 livebirths respectively by ensuring all their livebirths use hospitals within 2 hours. On the other hand, Samburu, Turkana and West Pokot counties can reduce their NMRs by approximately 12 deaths per 1,000 livebirths by ensuring all births are within two hours of a VLBW hospital.

**Conclusion:** Understanding the distribution of hospitals and geographic access to these services is critical in estimating the underserved. At the continental level, geographic access is significantly associated with variation in MMR but not NMR. Using Kenya as an example shows that accessibility models can be improved by evaluating the services available in hospitals in addition to using improved data on covariates, thus allowing for better assessment of how access relates to mortality. As such, Kenya can reduce MMR by 240.7 per 100,000 livebirths and NMR by 5.2 per 1,000 livebirths by ensuring universal access to CS and VLBW hospitals. This highlights the importance of implementing interventions that bridge geographic accessibility gaps, especially in the marginalized populations across Africa. However, there are still challenges with availability and quality of hospital services data in addition to reliable data on outcomes such as mortality and ultimately, improving the quantification of impact geographic access to hospitals on health outcomes will be dependent on improving data collection tools.

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# LIST OF ACRONYMS

| ACRONYM | Meaning |
|---|---|
| AFEM | African Federation of Emergency Medicine |
| AIDS | Acquired Immunodeficiency Syndrome |
| ALMA | African Leaders Malaria Alliance |
| AMTSL | Active Management of The Third Stage Of Labour |
| ANC | Antenatal Care Attendance |
| ASTER | Advanced Spaceborne Thermal Emission and Reflection Radiometer |
| BEmONC | Basic Emergency Obstetrics and Neonatal Care |
| CBH | Complete Birth History |
| CEmONC | Comprehensive Emergency Obstetrics and Neonatal Care |
| CIN | Clinical Information Network |
| CPAP | Continuous Positive Airway Pressure |
| CS | Caesarean Section |
| CSREF | Centre de Santé de Référence |
| DALY | Disability Adjusted Life Years |
| DEM | Digital Elevation Model |
| DHIS2 | District Health Information System Version 2 |
| DHS | Demographic and Health Surveys |
| EA | Enumeration Area |
| EMFK | Emergency Medicine Foundation of Kenya |
| EmOC | Emergency Obstetric Care |
| EmONC | Emergency Obstetrics and Neonatal Care |
| EQUIST | Equitable strategies save lives tool |
| ESRI | Environmental Systems Research Institute |
| FBO | Faith Based Organization |
| FCA | Floating Catchment Area |
| FPR | Facility to Population ratio |
| GDP | Gross Domestic Product |
| GIS | Geographic Information System |
| GoK | Government of Kenya |
| GPS | Global Positioning Systems |
| GPW | Global Population of the World |
| GRUMP | Global Rural-Urban Mapping Project |
| HDSS | Health and Demographic Surveillance Systems |
| HHFA | Harmonized Health Facility Assessment |
| HIV | human immunodeficiency virus |
| HMIS | Health Management Information Systems |
| HSSP | Health Sector Strategic Plan |
| ICD-10 | International Classification of Diseases, 10th Revision |
| IHME | Institute for Health Metrics and Evaluation |
| IPTp | Intermittent Preventive Treatment for Malaria During Pregnancy |
| IV | Intravenous Fluid |
| KDH | Kilifi District Hospital |
| KePH | Kenya Essential Package for Health |
| KFS | Kenya Forestry Service |
| KHDSS | Kilifi Health and Demographic Surveillance System |
| KMC | Kangaroo Mother Care |
| KMFL | Kenya Master Facility List |

| ACRONYM | Meaning |
|---|---|
| KWS | Kenya Wildlife Services |
| LBW | Low Birthweight |
| LMIC | Low- and middle-income countries |
| MAUP | Modifiable Areal Unit Problem |
| MFL | Master Facility List |
| MICS | Multiple Indicator Cluster Surveys |
| MMEIG | Maternal Mortality Estimation Inter-Agency Group |
| MMR | Maternal Mortality Rate |
| MoH | Ministry of Health |
| NCD | Non-Communicable Diseases |
| NGO | Non-Governmental Organization |
| NHIF | National Hospital Insurance Fund |
| NMR | Neonatal Mortality rate |
| NTD | Neglected Tropical Disease |
| NUHDSS | Nairobi Urban Health and Demographic Surveillance System |
| OCHA | Office for the Coordination of Humanitarian Affairs |
| OSM | OpenStreetMaps |
| PEPFAR | President's Emergency Plan for AIDS Relief |
| PPH | Post-Partum Haemorrhage |
| RAMOS | Reproductive Age Mortality Surveys |
| RCMRD | Regional Centre for Mapping Resources for Development |
| RFE | Rainfall Estimates |
| RMNH | Reproductive Maternal and Neonatal health |
| SAE | Small Area Estimation |
| SARA | Service Availability and Readiness Assessment |
| SARAM | Service Availability and Readiness Assessment Mapping |
| SBA | Skilled Birth Attendance |
| SBH | Summary Birth History |
| SDG | Sustainable Development Goals |
| SSA | Sub-Saharan Africa |
| ST-GPR | Spatio Temporal Gaussian Process |
| TB | Tuberculosis |
| U5M | Under 5 Mortality |
| UHC | Universal Health Coverage |
| UI | Uncertainty Interval |
| UN | United Nations |
| UNDP | United Nations Development Programme |
| UNFPA | United Nations Population Fund |
| UNICEF | United Nations Children's Fund |
| UNIGME | UN Inter-agency Group for Child Mortality Estimation |
| UNPD | United Nations Population Division |
| USAID | United States Agency for International Development |
| UTM | Universal Transverse Mercator |
| VGI | Voluntary Geographic Information |
| VIF | Variance Inflation Factor |
| VLBW | Very Low Birthweight |
| WGS | World Geodetic System |
| WHO | World Health Organization |
| WoCBA | Women of Childbearing Age |

# Chapter 1: Background and Literature Review

## 1.1 Introduction

In September 2015, 17 Sustainable Development Goals (SDGs) were adopted by the UN general assembly as a framework for promoting development and population well-being [UN, 2016]. One of the goals, SDG 3, aims to ensure healthy living and promote population wellbeing. Achieving this goal is dependent on ensuring access to health services under the overarching concept of Universal Health Coverage (UHC) [WHO & World Bank Group, 2013]. Access has three distinct components: recognizing the need to seek care, accessing a location where health services are provided (geographic accessibility) and obtaining quality services once at the facility [McCarthy & Maine, 1992; Thaddeus & Maine, 1994]. Geographic access plays an important role in the use of health services, given its ability to explain the interaction between the supply of health services and the demand by the population [Ensor & Cooper, 2004]. It is driven by factors such as distance, travel time, socio economic status, transport modes and transport infrastructure, all of which affect ability of patients to reach services [Donnell, 2007]. The role of geographic access is particularly important in sub-Saharan Africa (SSA), where populations are often sparsely distributed and services scarcely available. Thus, in many instances, metrics of geographic accessibility have been used to identify populations marginalized from health services, while also serving as a metric of measuring equity in health access [Noor et al., 2003; Peters et al., 2008; Odu et al., 2015].

Maternal and neonatal deaths have been disproportionately high in SSA, despite there being well-known interventions that can tackle these deaths. It is estimated that 73% of the maternal deaths are due to direct obstetric causes [Say et al., 2014], while 45% of all under 5 deaths occur in the neonatal period and are mainly due to prematurity and intrapartum related complications [UNIGME, 2017]. These are time-sensitive conditions that typically require higher-level care at hospitals and ensuring geographic accessibility to these services will be key if deaths are to be reduced [WHO et al., 2009; Gabrysch et al., 2012].

This introductory chapter is aimed at providing an understanding of the concept of geographic access and its relationship with maternal and neonatal health. Section 1.2 reviews the concept of good health, progress in achieving health targets and where the challenges are. This is then followed by a review of interventions required to bridge gaps with a specific focus on universal health coverage (UHC) in Section 1.4. Section 1.5 discusses the role of access in achieving UHC while narrowing down to the significance of geographic accessibility. Section 1.6 introduces the concept of maternal and newborn health, highlighting in detail the burden of maternal and neonatal mortality in SSA, their measurement and the interventions that can reduce these deaths. Section 1.7 focuses on reviews of previous studies that are critical in framing research questions. First is a review of methods used to define geographic access to comprehensive emergency obstetric and neonatal care (CEmONC) services. The second is a review of transport modes to these hospitals based on shortcomings of the first review. Section 1.10 is a review of the role geographic access plays in explaining the variation in maternal and neonatal mortality. Finally, in Section 1.11, a summary of the literature, study justification and research questions are presented.

## 1.2 The concept of good health

Good health refers to a state of complete social, physical and mental wellbeing and is important in promoting overall population wellbeing [WHO, 2015a]. First, healthier people are more productive, with work absenteeism being lower, which increases overall population development and promotes the development of other sectors like food production. Secondly, healthier school-going children are more likely to have greater cognitive capacity for learning and improved school attendance, something which increases labour productivity later in life, in turn, contributing to economic development [Bloom et al., 2004]. Thirdly, increased life expectancy provides an incentive for retirement savings which improves savings, in turn boosting investment, economic growth and overall population wellbeing. Lastly, reduction in infant and child mortality rates boosts population growth, and if combined with reduced fertility rates, spurs economic growth [Jamison et al., 2013].

Promoting good health has therefore ranked high within different development agendas. Currently, the global development agenda is driven by 17 Sustainable Development Goals (SDGs), adopted by the UN general assembly in 2016 [UN, 2016]. Just as it was in the era of the Millennium Development Goals (MDGs), promotion of good health is recognized as key in achieving SDGs. SDG 3 specifically identifies the need to "*Ensure healthy lives and promote well-being for all at all ages*" and is anchored on 13 cross-cutting targets as shown in Table 1.1 [WHO, 2015a]. While the health-related SDGs do not directly address other determinants of population health and wellbeing, the importance of other societal factors such as poverty, education, housing and gender equality is captured in other SDGs. Achieving good health and population wellbeing, therefore, requires not only achieving SDG 3 but also ending poverty (SDG 1), ensuring access to quality education (SDG 4), promoting gender equity (SDG 5) and universal access to clean water and sanitation (SDG 6). Good health and wellbeing are also dependent on reducing inequalities between and within countries (SDG 10) and promoting peace (SDG 16).

The SDGs, therefore, emphasize the importance of reducing inequities. The burden of ill health has traditionally been disproportionately borne by SSA countries. This is manifested in observed lower life expectancy - a measure of overall population wellbeing – in the region. In 2017, life expectancy was estimated to be 61 years in SSA, compared to low-income countries in South Asia which had a life expectancy of 69 years [UNDP, 2013; Lozano et al., 2018]. The poor outcomes in SSA are primarily driven by the burden of traditional challenges such as infectious diseases, in addition to emerging chronic diseases, increasing burden of injuries and mental health disorders [Dicker et al., 2018; Roth et al., 2018]. These challenges are discussed in detail in the next section.

Table 1.1 Health related sustainable development goals. The targets are numbered in bold

| Target | Description |
|---|---|
| **3.1** | By 2030, reduce the global maternal mortality ratio to less than 70 per 100,000 live births |
| **3.2** | By 2030, end preventable deaths of newborns and children under 5 years of age, with all countries aiming to reduce neonatal mortality to at least as low as 12 per 1,000 live births and under-5 mortality to at least as low as 25 per 1,000 live births |
| **3.3** | By 2030, end the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases and combat hepatitis, water-borne diseases and other communicable diseases |
| **3.4** | By 2030, reduce by one third premature mortality from non-communicable diseases through prevention and treatment and promote mental health and well-being |
| **3.5** | Strengthen the prevention and treatment of substance abuse, including narcotic drug abuse and harmful use of alcohol |
| **3.6** | By 2020, halve the number of global deaths and injuries from road traffic accidents |
| **3.7** | By 2030, ensure universal access to sexual and reproductive health-care services, including for family planning, information and education, and the integration of reproductive health into national strategies and programmes |
| **3.8** | Achieve UHC, including financial risk protection, access to quality essential health-care services and access to safe, effective, quality and affordable essential medicines and vaccines for all |
| **3.9** | By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination |
| **3.a** | Strengthen the implementation of the World Health Organization framework convention on tobacco control in all countries, as appropriate |
| **3.b** | Support the research and development of vaccines and medicines for all. |
| **3.c** | Substantially increase health financing and the recruitment, development, training and retention of the health workforce in developing countries, especially in the least developed countries and small island developing States |
| **3.d** | Strengthen the capacity of all countries for early warning, risk reduction and management of national and global health risks |

**Footnote:** AIDS - Acquired Immunodeficiency Syndrome.

## 1.3 The burden of ill health in sub-Saharan Africa

Infectious diseases are still the main causes of morbidity and mortality in SSA, with malaria, HIV/AIDS, respiratory illnesses and tuberculosis ranking among the top causes of disability-adjusted life years [Kyu et al., 2018]. AIDS-related deaths in the region have declined, from a peak of 700,000 in 2004 to 300,000 in 2017, but the region still accounted for 66% of the new HIV infections in 2017 [UNSAIDS, 2018]. Similarly, malaria mortality has declined in the region since 2000, but the region still accounts for more than 90% of the global burden [WHO, 2019]. SSA also ranks highest in the burden of other infectious diseases like tuberculosis, diarrheal diseases and respiratory infections. The biggest risks are increasing incidences of diseases, drug resistance, and epidemics such as the recent West African Ebola outbreak and the ongoing severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) transmission.

Globally, maternal and child mortality has been on the decline. Between 1990 and 2015, global maternal and child mortality rates declined by 44% and 53%, respectively, falling short of the targeted 75% and 66% drops in the MDG [UN, 2016]. In SSA, the neonatal period – the first 28 days of life - is the most vulnerable time for child survival. Between 1990 and 2015, the rate of decline in under 5 mortality was slowest in the neonatal period, and in 2015, deaths in this period accounted for 37% of all under 5 deaths [Victora et al., 2016]. This translates to over a million African babies dying in the first 4 weeks of life – with up to half occurring in the first six days of life. The region also accounted for 48% of the global maternal deaths in 2016 [Kassebaum et al., 2016], with the cases being highly localized in few high burden countries.

The landscape of health in SSA is changing rapidly. While infectious diseases, malnutrition, maternal and child morbidity have been persistent challenges, changes in lifestyle (e.g., tobacco and alcohol consumption and poor diet), more sedentary lifestyles and increased urbanisation have increased the risks of chronic/non-communicable illnesses (NCDs) [WHO, 2019]. Modelled estimates project that by 2030, NCDs will account for half of all the deaths in SSA, as prevalence of cancers, diabetes, hypertensive diseases and obesity increase [Mathers & Loncar, 2006]. Injuries are also increasing in the region and in 2015, deaths due to injuries increased by 20% from 1990, with 15% rise in DALYs in the same period. These were mainly caused by increase in road traffic injuries (32% increase), self-harm (87% increase) and violence (58% increase) [Roth et al., 2018].

Achieving the goals aimed at tackling these challenges in SSA has traditionally been hampered by overall health system challenges. These include i) inequities in service provision, which means there is population-level marginalisation from health services based on geography or their socio-economic and demographic status [Whitehead, 1992; WHO, 1996; Braveman & Gruskin, 2002; Braveman, 2006]; ii) poor quality of services limiting the ability to achieve desired health outcomes [Kruk et al., 2016b]; and iii) unresponsive and inefficient health systems, especially when faced with the emergence and re-emergence of diseases  [Baize et al., 2014; Merler et al., 2015].

Progress in improving health in SSA has been encouraging but still falls short of the targets. Accelerated progress will therefore require expanding access to immunisation services, preventive measures such as contraceptive use, improving health seeking behaviour for those needing care and improving the capacity of health systems to provide quality health services. Moreover, the region needs to limit the negative outcomes of both infectious diseases and NCDs. In addition to adopting the SDGs, there have been several African led initiatives aimed at galvanising resources for improving the health status of the continent as summarised in Table 1.2.

Table 1.2 Strategic options and goals for improving healthcare in Africa. Shows the sustainable development goals with the corresponding initiatives in Africa. The sustainable development goals are numbered in bold.

| **Description** | **Related SDGs and Targets** [UN, 2016] | **Examples of Africa Led Initiatives** | **Main Interventions** |
|---|---|---|---|
| Control communicable diseases. These include HIV, tuberculosis (TB), malaria and other communicable diseases including neglected tropical diseases (NTDs). Includes eliminating vaccine preventable diseases like measles | **3.3:** By 2030, end the epidemics of malaria, AIDS, TB, and NTDs including combating water-borne and other communicable diseases | The African Union led roadmap on shared responsibility and global solidarity for TB, AIDS, and malaria response in Africa [African Union, 2012]. Aims at enhancing leadership and governance, ensure access to services and diversify financing for TB, AIDS and malaria initiatives; The African Leaders Malaria Alliance (ALMA), a coalition of 49 African heads of state working to eliminate malaria by 2030. This involves ensuring access to key interventions [ALMA, 2009]; Roadmap for Implementing the Addis Declaration on Immunization, aims at generating and sustaining commitment and funding that overcome access barriers to immunization [WHO & African Union, 2017]. | Control of communicable disease |
| Prevent the spread and minimize the effect of outbreaks from existing, rare and emerging diseases including emergencies | **3.d** Strengthen the capacity of all countries, in particular developing countries, for early warning, risk reduction and management of national and global health risks | African Federation for Emergency Medicine [Reynolds et al., 2014]. Aims to advance advocacy and policy that bridge gaps in access to emergency services; African Public Health Emergency Fund [WHO-AFRO, 2013]. | Responsive health systems for prevention, treatment and surveillance |

Table 1.2 Continued…

| **Description** | **Related SDGs and Targets** [UN, 2016] | **Examples of Africa Led Initiatives** | **Main Interventions** |
|---|---|---|---|
| Reduce maternal, neonatal, and child deaths. | **3.1** By 2030, reduce the global maternal mortality ratio to less than 70 per 100 000 livebirths; **3.2** By 2030, end preventable deaths of newborns and children aged under 5 years, with all countries aiming to reduce neonatal mortality to at least as low as 12 per 1000 livebirths and under-5 mortality to at least as low as 25 per 1000 livebirths | The Campaign on Accelerated Reduction on Maternal Mortality in Africa (CARMMA) [African Union, 2009]. Main aim is to expand the availability of maternal health services | Access to quality health services during pregnancy at childbirth and after birth including immunization. Improve the management of childhood illnesses |
| Promote mental health wellbeing and reduce the risk of NCDs. Provide essential treatment for NCDs | **3.4** By 2030, reduce by 1/3 premature mortality from non-communicable diseases through prevention and treatment, and promote mental health and wellbeing | The Africa Tobacco Control Regional Initiative [WHO, 2012a] | Campaigns that target reduction of obesity, physical inactivity, unhealthy diets, smoking, alcohol consumption, substance abuse; address discrimination and reduce violence; reduce exposure to environmental health hazards; Early diagnosis and management of NCDs |
| Reduce incidence of injuries and interpersonal violence and discrimination | **3.6** By 2020, reduce by half the number of global deaths and injuries from road traffic accidents; **5.2** Eliminate all forms of violence against women and girls and all types of exploitation. | The African Plan for the Decade of Action for Road Safety 2011–20 [African Union, 2015]. | Improve road safety through campaigns, better infrastructure, enforcement of traffic rules and regulations, improve public transport system, alcohol and drugs control |

Table 1.2 Continued…

| **Description** | **Related SDGs and Targets** [UN, 2016] | **Examples of Africa Led Initiatives** | **Main Interventions** |
|---|---|---|---|
| End all forms of malnutrition | **2.2** By 2030, end all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children aged under 5 years, and address the nutritional needs of adolescent girls, pregnant and lactating women, and older people. | African Leaders for Nutrition (ALN). A high-level political engagement meant to advance nutrition in the continent. Was endorsed in January 2018 [AFDB, 2018]. | Ensuring food security and promotion of national nutrition programmes |
| Reduction of fertility to replacement levels | **3.7** By 2030, ensure universal access to sexual and reproductive health-care services, including for family planning, information and education, and the integration of reproductive health into national strategies and programmes. | The African Union Policy Framework on sexual and reproductive health rights. Adopted in 2006, aims to advance reproductive health initiatives aimed at overall reduction in maternal and neonatal mortality [African Union, 2006]. | Access to family planning including reduction of teenage pregnancies; promote sexual education; reduce gender-based violence |

**Footnote:** AIDS - Acquired Immunodeficiency Syndrome; HIV- human immunodeficiency virus; TB – Tuberculosis; SDGs – Sustainable development goals.

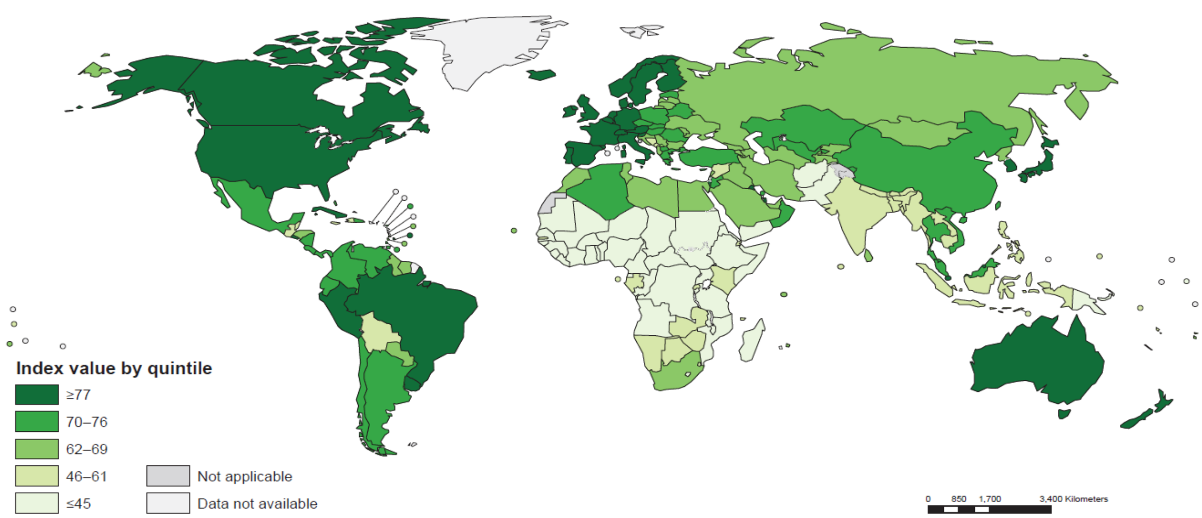
Given the challenges to healthcare in Africa, it is no surprise that health features prominently as a political issue as highlighted in Table 1.2. Commitment to improving health is informed by the recognition that everyone should receive the health services that they need when they need them. The benefits of improving health is expected to have enormous benefits in terms of longer and productive lives in the continent. Besides, stronger health systems that can prevent, detect and respond effectively to various challenges can reduce the disruptions and economic costs of such events. Making health services affordable can also reduce the financial hardships related to illnesses that in turn improves social cohesion and reducing poverty. These factors appeal to the concept of attaining UHC, which aims to ensure everyone has access to healthcare without any financial hardships [WHO & The World Bank, 2017a]. Attaining UHC within SSA will therefore be critical if good health is to be achieved. The role of UHC is therefore discussed in the next section.

## 1.4 The concept of Universal Health Coverage (UHC)

UHC exists when everyone has access to quality health services without facing any financial hardships. This definition is broad, and by default covers the broad range of care, from preventive, treatment and palliative care services. It ensures there's equity in geographical distribution of services, while the health facilities themselves are equipped and staffed adequately. As the need to pay for services at the point of care can discourage people from using services, UHC also aims to ensure that incentives such as compulsory pre-payments (taxes, insurance schemes and government charges) are put in place in a manner that protects the poor and vulnerable from financial hardships [WHO & The World Bank, 2017b]. Several countries have set up varied initiatives to achieve UHC. The first widely documented drive towards UHC was the tax financed national health services in the UK launched in 1948. Others include the nationwide universal coverage reforms in Japan and the Korean national health insurance launched in 1977. Several countries in Africa have also launched initiatives aimed at achieving UHC, such as the Zambian free healthcare for all launched in 2006, the Ghana National Health insurance scheme in 2008 and the Kenyan 2022 UHC drive launched in 2018. The successes seen in achieving UHC such as in the UK and Japan have seen it being adopted as a key health related goal, but more importantly, it is seen as key towards achieving all the other targets of SDG 3 [WHO & The World Bank, 2015].

A 2017 global assessment of national level UHC attainment used a composite measure covering 16 tracer indicators spanning several reproductive, maternal, newborn and child health (RMNCH) factors, infectious diseases, non-communicable diseases, service capacity and access to care. Majority of the countries which performed poorly were in SSA, and overall, the region had the lowest UHC index, at 42, compared to 53 in Southern Asia, 77 in Europe, North America and Eastern Asia with 77 [WHO & The World Bank, 2017a]. The variation in UHC index attainment is shown in Figure 1.1. Out of the four indicators, SSA performed poorest in the service capacity and access sub-index at 27. The access sub index was also the one with the greatest gradient across the countries, from as low as 27 to 99 in Eastern Asia [WHO & The World Bank, 2017a].

Figure 1.1 National level UHC index for 183 countries [WHO & The World Bank, 2017a].



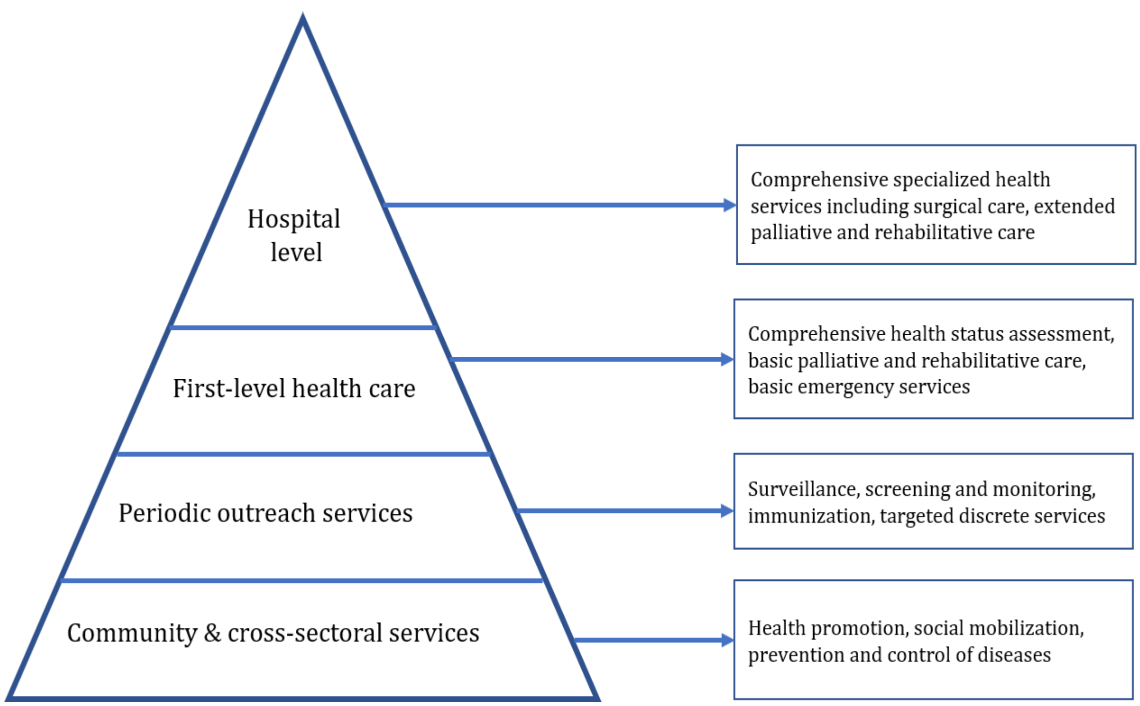

The poor performance in the UHC index in SSA points to challenges in creating enabling environments, community behaviour practices and poor access to life saving health services. Critically, there are still significant gaps in coverage of key health services. Despite absolute increases in health spending within the region in the MDG period, spending is still heavily reliant on out of pocket expenses and development assistance, putting millions of SSA residents at risk of impoverishing and catastrophic health expenditures [Dieleman et al., 2017]. Health systems in the region also perform poorly [WHO, 2007]. An efficient health system intends to achieve health equity, responsiveness, efficiency, quality, financial risk protection and sustainability [Gwatkin et al., 2004; Hongoro & McPake, 2004; Victora et al., 2004].

Health challenges in SSA countries are diverse and there is no "one size fits all" approach to achieving UHC. Strategies are dependent on local circumstances but overall, these will be dependent on ensuring there is more and better spending for effective financial protection, using strategies that focus on the poor, strengthening health security, promotion of good governance, strengthening health research and innovation in the region and putting in place people-centred services that provide quality care. Countries will need to develop their own national health strategies that aim towards achieving UHC. Although experiences in Africa are still emerging, countries within the region can learn from other high-income countries, Latin America and countries in Asia that have achieved UHC while still classified as middle-income countries (e.g. South Korea, Sri Lanka and Thailand) [Hogan et al., 2018]. These countries focused on design and implementation of schemes and packages that enabled provision of quality health services in a geographically accessible manner. Development of Primary Health Care (PHC), where services and benefits are available at different levels of care was therefore key in achievement of UHC. The next section aims to describe the service delivery structure in SSA. This aims to provide a general introduction, but health service delivery may be complex given the different disease manifestations and complexities. The cascade of service delivery within the maternal and newborn care domain will therefore be described in detail in Section 1.6.5.

## 1.5 Health service delivery in sub-Saharan Africa

Health service delivery refers to the interface between people and the health system [WHO, 2010a], and its organisation determines whether the inputs lead to desired outputs [Berman et al., 2011; Bold et al., 2011]. Since the Alma-Ata declaration in 1978 the concept of pluralistic service delivery systems has been promoted. Although there are no universally acceptable definitions of these services, they are typically organised in a hierarchical manner with increasing sophistication from the community health workers, health posts, health centres to the hospitals [WHO, 1978] as shown in Figure 1.2. Community services are the first responders and seek to create awareness at the community level. The periodic outreach services include surveillance, immunization and targeted discrete services. They also identify services that require referral to higher levels of care. Although each component can be seen as separate, they must work together in order to make a significant impact on the population [Kobusingye et al., 2006].

Figure 1.2 Structure of health service delivery including the services offered along the continuum of care [WHO, 1978].



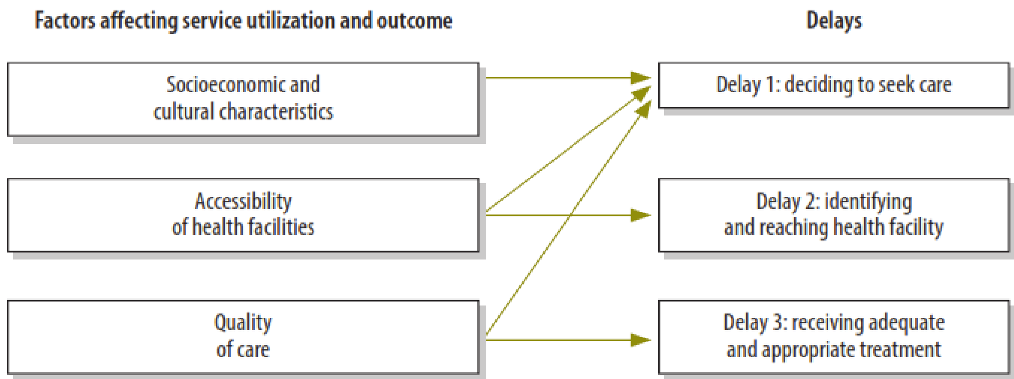
In addition, distinctions between health service providers exist, with the most common being whether they are either public or private [van Damme et al., 2011]. In almost all health systems, the public sector run by national governments, local authorities or other non-governmental organisations (not for profit) makes up the backbone of the health systems [Montagu & Goodman, 2016]. However, over the last 20 years, the significance of private health providers has been increasing, and their overall role in attaining UHC cannot be ignored [Kruk et al., 2016a; McPake & Hanson, 2016; Montagu & Goodman, 2016]. Attaining UHC is therefore pegged on ensuring that the different levels of care are accessible.

### 1.5.1 Access to health care

Access to health care is where patients in need of services can obtain them without any financial or physical barriers [Evans et al., 2013]. Access to health care can be defined in several ways. In a very narrow sense, it refers to how far people live from health facilities, while in a broader sense it refers to the fusion between availability, accessibility, affordability and acceptability [Guagliardo, 2004]. Availability deals with the supply side of health services for a given demand population [McLafferty, 2003]. Accessibility, on the other hand, includes the physical barriers that limit the ability to reach health service providers. These include distance, travel time, land use and modes of transport. Affordability refers to the financial aspects affecting the ability to seek care, for example, ability to pay for services or pay for modes of transport to health facilities. Finally, acceptability refers to the patients' interaction with the health system in terms of choice [Guagliardo, 2004].

Access to essential services remains a challenge worldwide, with estimates indicating that at least 400 million people lack access to care [WHO & The World Bank, 2015]. Barriers towards receiving appropriate care can be conceptualized using the three-delay model shown Figure 1.3 [Calvello et al., 2015]. The model identifies three critical time points where lack of appropriate intervention may lead to progression of the disease to disability and mortality. These barriers manifest themselves in factors described in the next section.

Figure 1.3 The delay model for accessing emergency care [Evans et al., 2013].




User characteristics such as education, wealth, severity of illness, age, ethnicity, urbanisation and female autonomy can be significant barriers towards accessing healthcare as shown in Table 1.3. The relationship between these factors and utilisation of facilities, however, varies depending on the setting. There is a consensus that increasing travel time to health facilities reduces the probability of seeking formal health services ("Decay effect") [Taylor, 1971], notably in rural areas where the physical separation between populations and service providers are extenuated. Other factors that affect geographic access include the condition of roads and weather conditions. However, once the physical barriers are overcome, poor quality of care at facility can also act as barriers to accessing services [Kruk et al., 2018].

Quality of care is influenced by many factors including health worker shortages, lack of adequate infrastructure and medical supplies, long waiting times [Mock et al., 2014; Ologunde et al., 2014] and weak referral systems [Atkinson et al., 1999; Bossyns et al., 2005; Abrahim et al., 2015]. Low quality of health facilities can result in patients bypassing the nearest hospital and seeking care in a private sector facility or hospitals. This imposes additional costs in terms of the services sought and transportation needs. Unfortunately, in some instances, even the alternative facility sought can also be of poor quality, and this can further delay timely access to care [Elmusharaf et al., 2017].

Table 1.3 Summary of barriers towards accessing health facilities

| Barrier | Factor | Source | Relationship |
|---|---|---|---|
| Cultural and socio-economic | Income/ Cost of services and transport | [Burton et al., 2011; Diaz et al., 2013; Broccoli et al., 2016] | Wealthier households associated with higher treatment seeking rates |
| | Poverty | [Chuma et al., 2007; Novignon & Nonvignon, 2012; Ibe et al., 2015; van Loenhout et al., 2017] | Poorer households associated with lower treatment seeking rates |
| | Education | [Cotter et al., 2013; Kyei-Nimakoh et al., 2017; Shrime et al., 2017] | Increasing education associated with higher treatment seeking rates |
| | Age | [Ewing et al., 2011; Ustrup et al., 2014] | Younger children likely to be taken to facilities |
| | The severity of the illness | [Taffa & Chepngeno, 2005; Chibwana et al., 2009; Grimes et al., 2011; Ustrup et al., 2014] | Utilization of health facilities is higher in groups where severity is perceived to be higher. |
| | Ethnicity | [Chaturvedi et al., 2009] | Varies by context |
| | Family decision maker | [Chaturvedi et al., 2009; Ologunde et al., 2014] | Varies by context |
| | Urbanization | [Romay-Barja et al., 2015] | Urban populations more likely to seek care |
| | Work commitments | [Grimes et al., 2011; Kyei-Nimakoh et al., 2017] | commitments prevent seeking care |
| | Religion | [Grimes et al., 2011; Ologunde et al., 2014] | Likely to vary by location |
| Accessibility | Distance/Travel time | [Grimes et al., 2011; Manongi et al., 2014; McKinnon et al., 2014; Bennett et al., 2016] | Results in the distance decay effect |
| | Seasonal variations | [Makanga et al., 2017] | In the wet season travel time to facilities may increase |
| | Condition of roads | [Makanga et al., 2017] | Increases delay in seeking services |
| | Transport availability | [Myers et al., 2017] | Transport unavailability reduces access |
| Quality of care | Inadequate skills | [Mock et al., 2014; Ologunde et al., 2014] | All delay service availability once patients present to the facility |
| | Staff shortages | [English et al., 2004; Knight et al., 2013; Kyei-Nimakoh et al., 2017] | |
| | Drug procurement/shortage problems | [Kangwana et al., 2009; Masters et al., 2013] | |
| | Poor Equipment | [English et al., 2004; Hsia et al., 2012; Adair-Rohani et al., 2013; Knight et al., 2013; Kyei-Nimakoh et al., 2017] | |
| | Irregular opening hours | [Exavery et al., 2014; Essendi et al., 2015] | |

### 1.5.2 Geographic accessibility to healthcare

Of the three delays (Figure 1.3; Table 1.3), geographic accessibility is significant in SSA because distance is a common challenge in many marginalised communities [Donnell, 2007]. Geographic access relates to movement from point of origin to the destination facility with required services and may be affected by various physical barriers. For example, distances may be long, transport may be slow or unavailable, elevation may reduce transport speeds or transport barriers such as forests, lakes and rivers may increase travel distances. These are well-known mobility barriers in SSA and community-based studies have reported their significance in delaying patients from reaching health service providers [Grimes et al., 2011; Manongi et al., 2014; McKinnon et al., 2014; Bennett et al., 2016]. As a result, several studies have reported the direct relationship between poor geographic access and mortality and will be reviewed in detail in Section 1.7. Therefore, attaining the health-related SDGs will be reliant on developing policy and advocacy aimed at overcoming geographic access barriers, particularly in SSA where a majority of the population reside in rural areas. At the very least, this requires the generation of geographic accessibility metrics, that provide a sound basis for identifying populations that may face difficulty in accessing health services.

Maternal and neonatal emergency services will be used as examples throughout this thesis to highlight variation in geographic accessibility in SSA for two main reasons: First, and most importantly, maternal and neonatal mortality rates are unacceptably high in SSA, compared to other regions despite the existence of well-known interventions. Secondly, it is estimated that 73% of all maternal deaths are due to direct obstetric causes [Say et al., 2014], while 45% of all under 5 deaths occur in the neonatal period and are mainly due to prematurity and intrapartum related complications [UNIGME, 2017]. These are time sensitive conditions that require provision of timely interventions in a well organised and coordinated manner. While care can be provided across a continuum that commences at the community level, most of these deaths can be averted by ensuring access to higher level emergency services. The next section is therefore focused on maternal and neonatal health including the service delivery structure, outcomes and methods of measuring these outcomes.

## 1.6 Maternal and newborn health

Maternal deaths are caused by several diseases and clinical conditions, most of which, as evidence suggest, can be managed by well-known interventions provided at health facilities. This section discusses the concepts of maternal and neonatal mortality, how they are measured, and the main causes and interventions needed to reduce the deaths. This forms a basis for understanding where services can be obtained within the continuum of health services described in Section 1.4, and the cascade of maternal service delivery is discussed.

### 1.6.1 Maternal mortality

Maternal mortality has traditionally been defined as death during pregnancy or occurring 42 days after termination of a pregnancy from any cause related to, or aggravated by, the pregnancy or its management but not from accidental causes [WHO, 2014a]. Maternal deaths result from either direct or indirect causes [WHO, 2014a]. Direct causes result from obstetric complications either during pregnancy, labour or postpartum. Indirect causes of deaths are those aggravated by diseases such as HIV/AIDS and malaria during pregnancy [Cross et al., 2010]. As such, the International Classification of Disease ($10^{th}$ revision) included a more practical definition of maternal deaths, where a pregnancy-related death was defined as the death of a woman while pregnant or within 42 days of termination of the pregnancy, irrespective of the cause of death. This definition includes accidental and incidental issues and makes it possible to have estimates without establishing the cause. The main measures of reporting maternal mortality are;

***Maternal mortality ratio (MMR):*** Number of maternal deaths for a specific period per 100,000 livebirths occurring in the same period.

***Maternal mortality rate (MM-rate):*** Number of maternal deaths for a specific period per 100,000 women of reproductive age (often taken as 15 to 49 years).

***Proportion of maternal deaths among female deaths (PMDF):*** Number of maternal deaths during a given period divided by total causes of death in women of reproductive age, usually defined as 15-49 years.

The most commonly used metric for measuring maternal mortality is MMR, which is a ratio of all maternal deaths occurring in a specific reference period to the total number of livebirths. The inclusion of livebirths in the denominator is because it is often difficult to collect information on the total number of pregnant women in a specific population [Graham & Campbell, 1992].

The three main sources of maternal deaths are vital registration systems (birth and death registration), service statistics and population-based surveys or surveillance. Vital registration systems are systems in which a government records all the vital events of its residents including birth and death information. It is therefore considered as the best source of mortality estimates [AbouZahr et al., 2010]. However, vital registration systems in SSA are faced by challenges of underreporting and misclassification [AbouZahr, 2011]. Hence, in SSA, estimates of maternal mortality are predominantly obtained from the Demographic and Health Surveys (DHS) and the Multiple Indicator Cluster Surveys (MICS) [Alkema et al., 2016; Kassebaum et al., 2016]. Such household surveys rely on either indirect [Graham et al., 1989] or direct [Graham et al., 2008] sisterhood methods, which despite having challenges of data collection and wide confidence intervals, provide the most reasonable estimates of population-level maternal mortality. In many low and middle-income countries, population-based surveys (DHS and MICS) act as the primary source of maternal mortality data [Mgawadere et al., 2017]. These surveys typically employ three methods;

**RAMOS** (Reproductive Age Mortality Surveys) which seek to identify all female deaths in the reproductive period, using household surveys, continuous population surveillance, health facility records, and key informants.

**Direct Estimation** which asks questions on maternal deaths in a household for recent time. These questions can be asked during a household survey or a during the censuses, although experience with the latter is limited [Mgawadere et al., 2017]. These two methods are resource-intensive as large sample sizes are required to infer population-based estimates with acceptably narrow confidence intervals.

**The sisterhood method** is an indirect method that attempts to overcome the large sample size requirements by interviewing adults on the survival of all their sisters. Sisterhood methods can be either direct or indirect. The indirect method [Graham et al., 1989], has fewer questions but provides a pooled estimate of maternal mortality at a point around 10-12 years before the survey. The direct method provides a more current estimate of about 3-4 years before the survey but has more questions and is more resource intensive. These surveys are often conducted at different time points in different countries/regions, but several organisations and institutions have invested in modelling estimates of maternal mortality. In addition, countries have been encouraged to collect maternal mortality during the census enumeration.

#### 1.6.1.1 The burden of maternal mortality

Baseline data for monitoring progress towards reducing maternal mortality are normally published by two main entities the United Nations Maternal Mortality Estimation Inter-Agency Group (MMEIG) [MMEIG, 2016], and the Institute for Health Metrics and Evaluation (IHME)

[GBD, 2017]. The MMEIG is comprised of the World Health Organization (WHO), the United Nations Population Fund (UNFPA), the United Nations Children's Fund (UNICEF), the World Bank Group and the United Nations Population Division (UNPD) set up as part of ongoing efforts to measure maternal mortality in countries lacking vital registration. Both sources rely on different input data, while at the same time employing different statistical models to produce comparable national level estimates of maternal mortality globally [Alkema et al., 2016; Kassebaum et al., 2016]. These differences will be discussed in detail in the next section.

#### 1.6.1.2 Description of MMR sources

*Estimation of maternal mortality by the IHME*

The IHME presents trends of MMR from 1990 to 2015 using 599 sources of maternal mortality data across 186 countries and islands. Two of the countries – Kenya and South Africa – had analysis undertaken at sub-national levels. The dataset used comprised of maternal deaths covering the full age range of 10-54 years. Data sources used were; vital registration systems, survey data, censuses and in some countries there were additional data from cancer registries and police records [Kassebaum et al., 2016]. The majority of the cause of death data were obtained from vital registration systems which were also the highest quality datasets, with each cause coded directly to the international classification of disease (ICD) detail coding system. For countries with poor vital registration systems, data from surveys and censuses were used. Given the significance of HIV in driving maternal deaths, a correction was introduced, and HIV related deaths produced separately. This was done by including estimates from a systematic review that quantified the proportion of pregnancy-related deaths that are attributed to HIV.

Maternal mortality was then modelled using a cause of death ensemble modelling approach (CODEm) that ran four separate models [Lozano et al., 2012]. Angola, Equatorial Guinea and Somalia did not have any input MMR data and estimates relied entirely on covariates. The covariates used were fertility rates, years of education, neonatal mortality, HIV deaths, antenatal care attendance (ANC), skilled birth attendance, hospital beds per 1,000 population, malnutrition, lag distributed income and prevalence of obesity which were also used to improve estimates in countries with data. These covariates were chosen because they significantly explain the variation in MMR.

Thus, the CODEm model runs four separate plausible statistical models which are used to identify the relationships between covariates and the outcome. Models used are a mixed effects linear model of the death rate, spatial-temporal gaussian process regression (ST-GPR), a model of the log of the death rate, mixed effects linear model of the cause fraction, and ST-GPR of the logit of the cause fraction [Kassebaum et al., 2016]. All plausible permutations of the selected covariates using these models are tested, and relationships verified using published literature. Covariates which displayed similarities in both the published literature and the regressions were retained in the model and were ranked based on a hold out predictive validity performance. Two separate CODEm models were run, one for countries with extensive and complete vital registration systems and another for all the countries combined [Kassebaum et al., 2016]. This was done so that countries with incomplete vital registration systems would not inflate confidence intervals, with results from this model restricted to only countries with such data and for the other countries, the model with all the data combined was used [Kassebaum et al., 2016].

Covariates used are shown in Table 1.4. In the relationship assessment, covariates were assigned to different levels in a hierarchical manner, where those that had a strong correlation assigned to level 1, those that are ecologically related at level 2 and at level 3, were covariates which are suspected to have a relationship but have not been proven. Covariates used were age-standardised and total fertility rates, years of education per person, income per capita, neonatal mortality rate per 1000 livebirths, HIV mortality in women of age 14-49, and the coverage of one antenatal care visit (ANC1), four visits of antenatal care (ANC4), skilled birth attendance, and facility delivery. At level 3 of the analysis, several covariates were used, and these were: Obesity prevalence, mortality death rate from fatal discontinuities and hospital beds per 1000 population as a proxy for the availability of BEmOC.

The national level estimates of MMR were categorised into six cause of death groups: hypertensive disorders; obstructed labour and uterine rupture; abortions, miscarriages and ectopic pregnancy; haemorrhage; sepsis and other maternal infections; and other maternal disorders [Kassebaum et al., 2016]. Systematic literature reviews were used to identify studies that examined the causes of maternal deaths, and where these were not enough, were supplemented by correspondence with Global Burden of Disease (GBD) collaborators or from specialised studies such as confidential inquiries. This information was used to supplement the pre-existing GBD cause of deaths database, often used to assess the causes of death [Lozano et al., 2012].

Table 1.4 Major differences in methodology and datasets used in modelling MMR by IHME and MMEIG

| **Indicator** | **IHME** | **MMEIG** |
|---|---|---|
| Number of sources | 599 | 203 |
| Number of countries | 186 | 171 |
| Age range of analysis | 10-54 | 15-49 |
| Missing data | Equatorial Guinea, Angola, Somalia | Angola, Cape Verde, Djibouti, Guinea Bissau, Somalia and South Sudan |
| Model | Single Bayesian Hierarchical Model | An ensemble of Linear mixed effects model and a Spatial-temporal model |
| Covariates used | Fertility rates, years of education, neonatal mortality, HIV deaths, antenatal care attendance (ANC), skilled birth attendance, hospital beds per 1,000 populations, malnutrition, lag distributed income and prevalence of obesity | GDP, total fertility rate and skilled birth attendance |

*Estimation of maternal mortality by the MMEIG*

The MMEIG also analyzed country-level maternal mortality as a consortium of international organizations led by the WHO. There were visible differences in MMR from those modelled by the IHME and this could be attributed to the differences in input data, processing methodology and assumptions used in the specification of the models. Overall, MMEIG used 203 sources of data for 171 countries and territories. Data were derived for maternal deaths within the 15-49 age range. There was no data for Angola, Cape Verde, Djibouti, Guinea Bissau, Somalia and South Sudan, while in some other countries, data was particularly sparse. Several datasets were excluded in the MMEIG analysis that were used in the IHME analysis, especially verbal autopsy and census data in LMICs, understandably due to the incompleteness of these sources of data in such countries (Section 1.6.1).

Similar to the IHME analysis, the MMEIG also leveraged on several data sources ranging from the vital registration systems, censuses, household surveys and specialised studies as sources of MMR. Most data sources were assumed to be subject to uncertainty and biases and the estimation process was aimed at accounting for both the random and systematic errors. For civil and vital statistics data, maternal deaths occurring in women of reproductive age were used. The coding was based on the ICD-9 and ICD-10 codes which included only deaths which occurred in the period corresponding to those in the definition of maternal deaths. One systematic bias in these datasets is potential misclassification of maternal deaths as a result of medical reporting which tends to undercount maternal deaths.

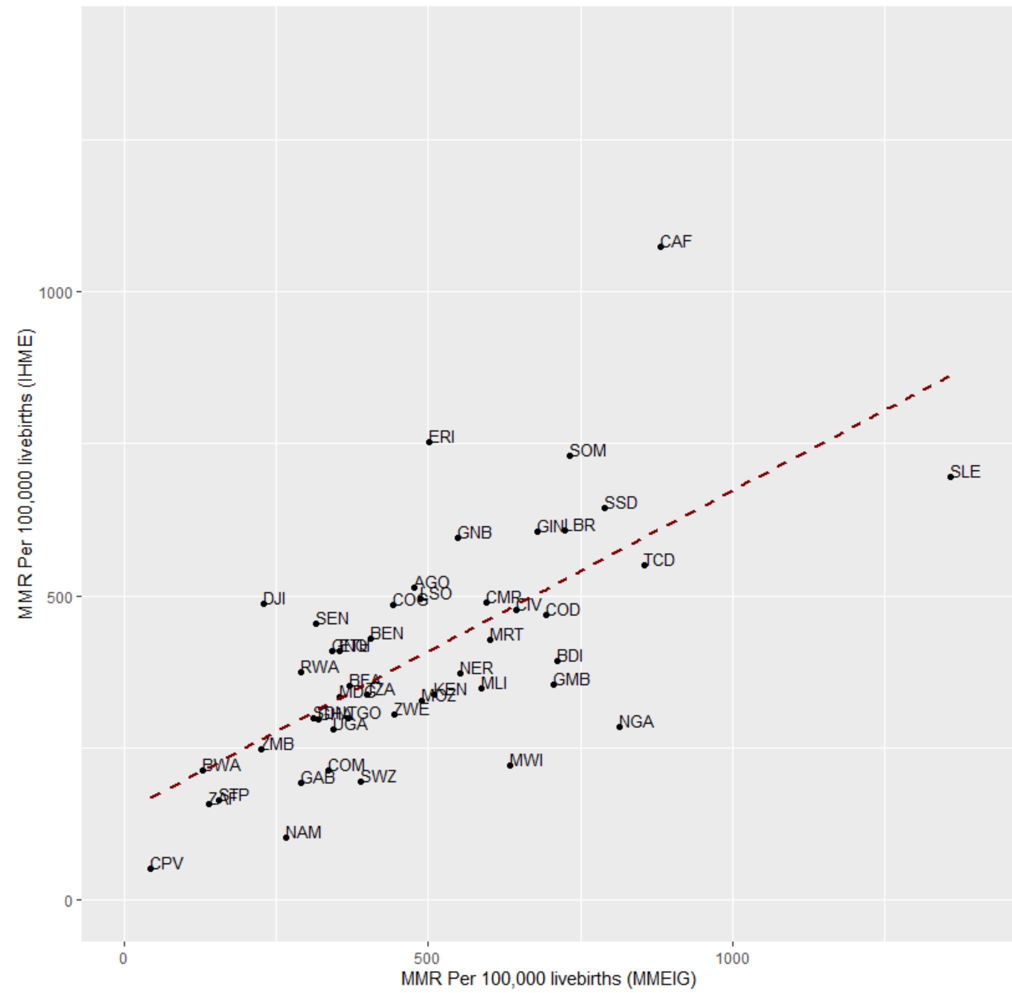
Covariates which explained variation in MMR were also used in the prediction and these were Gross Domestic Product (GDP), total fertility rate and skilled birth attendance, introduced in the modelling process to improve its predictive capability. A Bayesian hierarchical model was used to perform the maternal mortality estimations using the Markov Chain Monte Carlo for inference. In processing sibling history data, the MMEIG combined all the data from each survey, assigned weights to the midpoints and uniformly applied a correction factor for differences in survey data. The Bayesian model assumed that the proportion of non-HIV related maternal deaths was a linear function of country-specific covariates and a random intercept at country level [Alkema et al., 2016].

The Bayesian modelling approach used is implemented in such a way that its ability to track high quality data closely, handle data from surveys in earlier periods in addition to combining information from data and covariates in countries with limited data to produced covariate driven estimates. The model also eliminates the need for grouping countries based on the availability of data as is done in the IHME analysis. MMR was therefore computed as the sum of non-AIDS and AIDS related MMR, to capture the influence of AIDS as a significant aggregating factor. The non-AIDS regression model assumed that MMR is a linear function of the three covariates with the countries as random effects.

#### 1.6.1.3 Comparing the two MMR sources in SSA

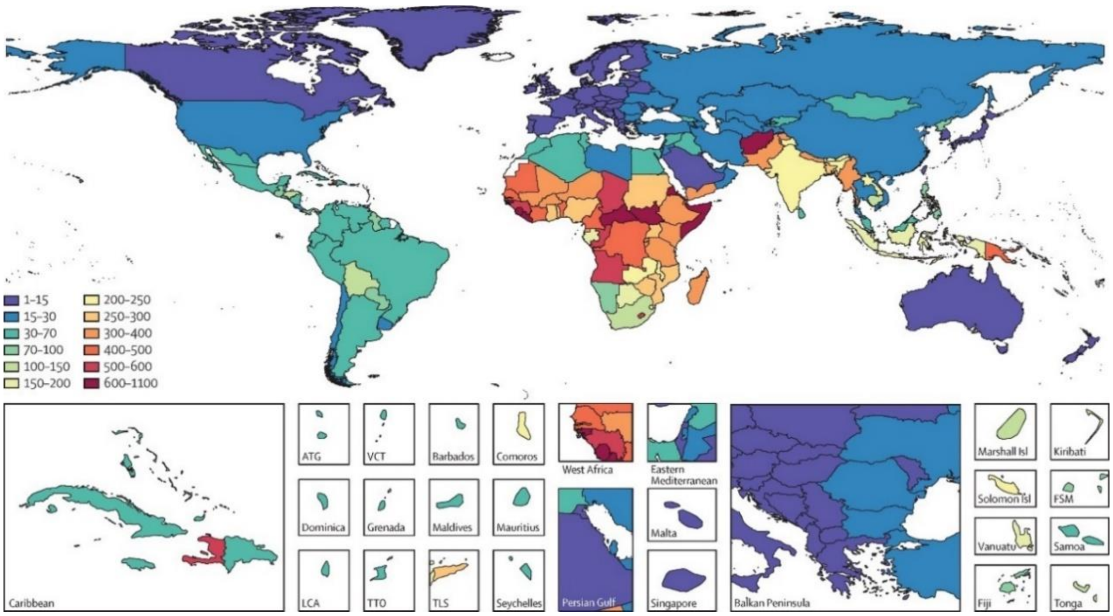
Both outputs are heavily reliant on modelling, and a comparison of the two is necessary. There were clear differences, especially in countries such as Chad, Burundi, The Gambia, Malawi, Nigeria and Sierra Leone, where absolute differences were greater than 300 deaths per 100,000 livebirths. The two datasets were relatively consistent in Somalia, São Tomé and Príncipe, Lesotho and Cape Verde where differences were less than 10. The overall correlation coefficient was 0.67 for 48 countries in SSA (Figure 1.4) and the major methodological differences shown in Table 1.4.

Figure 1.4 Correlation between national level estimates of MMR IHME and MMEIG estimates of 2016 MMR. The countries are labelled using their GAUL codes.




As shown above, both estimates differ based on the input data and methods of analyses, but the IHME dataset will be used because of more data inputs into the model and the narrower confidence intervals when it was compared to the MMEIG estimates [Kassebaum et al., 2014]. The latest round of analyses presented maternal mortality in 2015. Globally, the MMR was 196 per 100,000 livebirths, with LMICs accounting for 99% of the maternal deaths [Kassebaum et al., 2016]. There were significant variations in MMR at regional levels, with LMICs having MMR values that were 22 times higher than those in high-income countries (374.9 vs 16.9). SSA disproportionately accounted for 48% of the global maternal deaths. East Asia had the lowest MMR among developing regions, at 19 maternal deaths per 100,000 live births. National level variations are captured in Figure 1.5 [Kassebaum et al., 2016]. Four (Central Africa Republic, Somalia, Eritrea and Sierra Leone) of the five countries with an MMR greater than ten times the SDG target were in Africa.

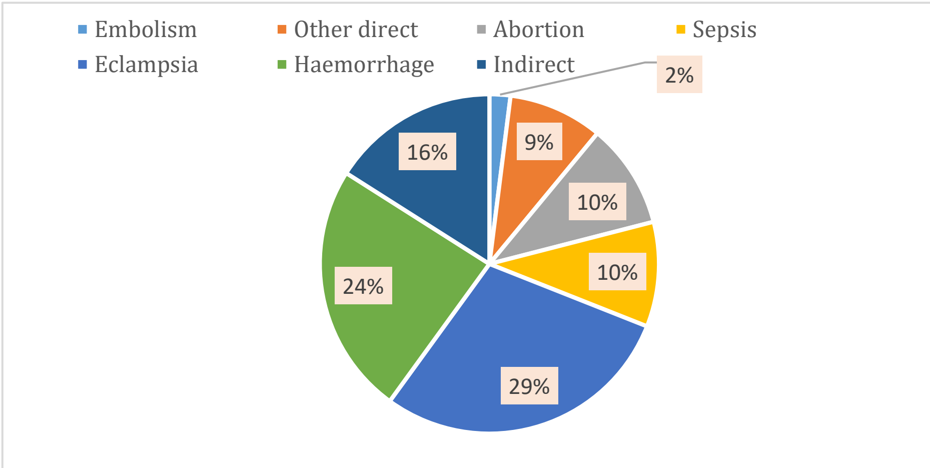
Figure 1.5 National level variations in MMR for all countries and territories in 2015 with increasing values from blue to brown [Kassebaum et al., 2016].




### 1.6.1.4 Causes of maternal mortality

The causes of maternal mortality can either be direct or indirect. The five direct causes are haemorrhage (often post-partum), eclampsia, sepsis, obstructed labour, complications due to abortions and other direct causes. The abortion category includes induced abortion, ectopic pregnancy and miscarriages. A recent systematic assessment of 417 datasets in 115 countries, found that 72% of all maternal deaths in SSA are due to direct obstetric causes (Figure 1.6) [Say et al., 2014]. The WHO ICD-10 (ICD-MM) classifies the category of indirect maternal deaths into deaths during pregnancy, and the puerperium [WHO, 2012b]. Indirect causes of death can be aggravated by other diseases and conditions such as malaria, HIV/AIDS or poor nutrition or from inadequate access to services, or other underlying social, economic and cultural factors [WHO, 2012b].

Figure 1.6 Causes of maternal mortality in SSA. Other direct causes refer to complications of delivery such as obstructed or prolonged labor [Say et al., 2014].




### 1.6.1.5 Direct causes

#### a) Hypertensive disease

Women in the puerperium or in pregnancy can suffer from preeclampsia, eclampsia and chronic hypertension [Say et al., 2014]. They tend to occur more frequently in the second half of pregnancies and treatment can be applied to alleviate the symptoms, but the well-known cure is the expedition of delivery. Approximately 30% of maternal deaths result from these conditions in SSA [Say et al., 2014]. Eclampsia and pre-eclampsia are more common in women who are in their first pregnancy, those who are obese, have diabetes and those with pre-existing hypertension [Filippi et al., 2016]. Managing/treating hypertensive disorders relies on the prevention of maternal cerebrovascular and cardiac complications while at the same time ensuring a continued uteroplacental flow of blood. The incidence of severe hypertensive diseases in SSA has been estimated at 1.6% and estimates of hypertensive disorders requiring hospitalisations are scanty, but a recent WHO consensus report highlighted the importance of hospitalising patients with such conditions, due to the need for close monitoring [WHO, 2011].

### b) Haemorrhage

Post-Partum Haemorrhage (PPH) is defined as a blood loss of 500ml or more within 24 hours of birth and is caused by excessive bleeding due of early loss of pregnancy, abnormality in the placental implantation or complications during childbirth. Postpartum haemorrhage causes approximately 40% of the maternal deaths in SSA which is the highest proportion [Khan et al., 2006]. The Active Management of The Third Stage Of Labour (AMTSL) guidelines outline interventions required to manage PPH [WHO, 2012c]. These include administration of oxytocin, delaying of cord clamping for at least 1-3 minutes and massaging of the uterine fundus after delivery. Administration of blood transfusion is critical in management of haemorrhage and ability to administer transfusions is one of the key comprehensive emergency obstetric and neonatal care (CEmONC) services, thus, reducing MMR requires ensuring adequate access to these services.

### c) Obstructed Labour

Obstructed labour can occur when the presenting part of the foetus is unable to progress into the birth canal even in the presence of strong uterine contractions [Dolea & Abouzahr, 2003]. Management of complications due to obstructed or prolonged labour include relief of obstruction, mostly by caesarean delivery or by assisted vaginal delivery, that in most cases should be done in hospitals [Hofmeyr, 2004; Bailey et al., 2017].

### d) Sepsis

Maternal sepsis refers to a life-threatening condition resulting from infection during pregnancy, childbirth, post-abortion. Sepsis, if poorly managed, can lead to adverse maternal outcomes like disability or death [WHO, 2017a]. Management of maternal sepsis requires the administration of parenteral antibiotics, performance of surgery and removal of retained products.

#### e) Ectopic Pregnancies

Ectopic pregnancy is a complication of pregnancy which occurs when the product of conception implants outside the uterine cavity (uterine tubes, abdomen, cervix and ovaries). It is one of the major causes of maternal mortality with an incidence rate of about 1%, especially in the first trimester of pregnancy and has a high mortality rate if surgical care is not administered.

### 1.6.1.6 Indirect causes

#### a) Complications of abortion

Morbidity with abortive outcomes comprise several diagnoses and also includes miscarriages [WHO et al., 2013]. Induced abortion can be a safe procedure, safer than childbirth if performed in the right method in a safe environment. In SSA, of the 5 million abortions that occur yearly, an estimated 71% are classified as unsafe [Ganatra et al., 2017]. Unsafe abortions often occur in poor medical conditions and complications arising from it often means patients require hospitalisation, with approximately 7.4% of the unsafe abortions needing hospital admissions [Singh, 2006].

#### b) Anaemia

Anaemia is the condition in which a mother's blood has too few red blood cells in the body and evidence suggests that it contributes to about 20% of the maternal deaths [Black et al., 2008]. Anaemia is common in pregnancy because of increased demand for iron by the growing foetus but is also exacerbated by infectious diseases like malaria, helminths and undernutrition. When it progresses to the severe form, i.e. with haemoglobin levels of less than 7.0 g/dl, the risks of mortality is elevated even further, as mothers are at risk of cardiac failure [Kavle et al., 2008; Daru et al., 2018]. A recent multicounty assessment in LMICs found that 2% of pregnancies were complicated enough to require hospitalisation, and these mothers had a risk of death that was three times those who were non-anaemic [Daru et al., 2018].

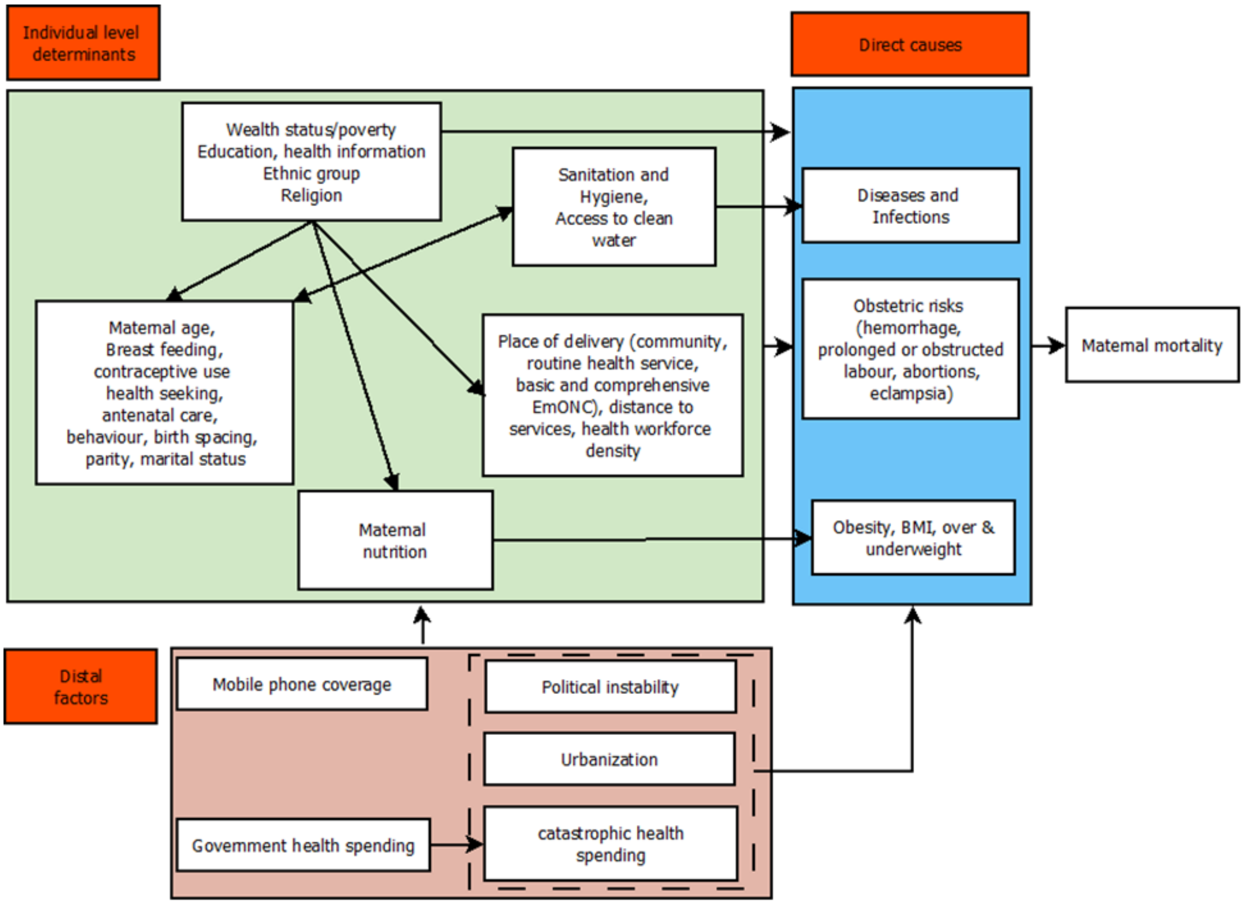
### c) Obesity and nutritional factors

Ideal maternal nutrition is critical for the survival of the mother in addition to promoting overall health and well-being. Maternal nutrition affects maternal and newborn survival outcomes in two different ways; anaemia (demand of foetus for iron) and folate deficiency. Obese women face increased risk due to conditions such as diabetes, cardiac problems and hypertension [Baeten et al., 2001]. Table 1.5 summarizes signal functions needed to manage direct obstetric complications, while Figure 1.7 conceptualizes how different factors affect maternal mortality and these will be described in detail in Section 1.6.3. The other indirect prevention mechanisms will be described in Section 1.6.3.

Table 1.5 Obstetric complications and their management. The shaded cells are those which are provided at hospitals with CEmONC services [WHO et al., 2009].

| **Complications** | **Signal Functions** |
|---|---|
| Haemorrhage | *Antepartum period:*<br>Perform blood transfusion<br>Perform surgery (e.g. caesarean section for placenta previa)<br>*Postpartum:*<br>Administer uterotonic drugs<br>Perform blood transfusion<br>Perform manual removal of placenta and retained products<br>Perform surgery (hysterectomy) for uterine rupture |
| Prolonged or obstructed labour | Perform surgery (caesarean section)<br>Administer uterotonic drugs, Perform assisted vaginal delivery |
| Postpartum sepsis | Administer parenteral antibiotics<br>Perform surgery for pelvic abscess<br>Remove retained products |
| Complications of abortion | *For haemorrhage:*<br>Perform blood transfusion<br>Remove retained products<br>*For sepsis:*<br>Administer parenteral antibiotics<br>Remove retained products<br>*For intra-abdominal injury:*<br>Administer parenteral antibiotics<br>Perform blood transfusion<br>Perform surgery |
| Pre-eclampsia or eclampsia | Administer parenteral anticonvulsants<br>Perform surgery (caesarean section) |
| Ectopic pregnancy | Perform surgery<br>Perform blood transfusion |
| Ruptured uterus | Perform surgery<br>Perform blood transfusion Administer parenteral antibiotics |

Figure 1.7 Conceptual framework showing the causal pathway between the determinants of maternal mortality. The arrows point how determinants interrelate based on their location in the pathway. Thus, distal factors affect intermediate factors, which in turn may exacerbate direct determinants. Direct determinants like infections/diseases or conditions can aggravate other direct causes or lead to maternal death. The conceptual framework is adapted and modified from [UNICEF, 2009; Filippi et al., 2016]




## 1.6.2 Neonatal mortality

In SSA, the neonatal period – the first 28 days of life- is the most vulnerable time for child survival. Between 1990 and 2015, under-5 mortality declined by 51%, but this rate of decline was slower in the neonatal period, and in 2015, deaths in the first 28 days of life accounted for 37% of all under 5 deaths [Victora et al., 2016]. The most commonly used scale for measuring neonatal and under 5 mortality is using the number of deaths per 1,000 livebirths. Neonatal mortality rate (NMR) therefore stands for neonatal deaths per 1,000 livebirths while under5 mortality refers to under5 mortality per 1,000 livebirths (U5M). This translates to over a million African babies dying in the first 4 weeks of life. In the next section, I provide data sources and methods used to define neonatal mortality with a specific focus on SSA. The section describes the recent use of demographic methods to estimate neonatal mortality at different scales.

Globally, the IHME relies on three main sources of data to model neonatal mortality. These are vital registration, complete birth histories and summary birth histories [Wang et al., 2014]. As with estimating maternal mortality, in many LMICs, vital registration systems are often incomplete and estimating under 5 mortality often relies on the use of direct and indirect methods applied to birth history data collected in household surveys, demographic surveillance systems (full or summary birth histories) and population censuses (summary birth histories) [Rajaratnam et al., 2010]. Records of complete birth histories (CBH) contain dates of birth and death, for all children and sampled women. On the other hand summary birth history (SBH) data have comparatively less information, as they only include mothers' reports of the number of children ever born and those who died without any information on the child's age or date of death [Silva, 2012].

To adequately monitor progress in neonatal mortality, age-specific estimates of under 5 mortality are required. This can directly be achieved using CBH data, however, SBH datasets lack enough input data to directly infer age-specific mortality estimates. SBH datasets, however, have the advantage of relative ease of collection, making them more widely available in sample surveys and censuses. To fully utilize these resources, different methods have been used for the indirect estimation of age-specific under-5 mortality using SBH data [Rajaratnam et al., 2010; Hill et al., 2015; Golding et al., 2017].

To estimate mortality in time, the standard SBH methods rely on simulated coefficients which are applied to the ratio of children dead to children ever born and later aggregated at different maternal ages. The IHME methods involve using pooled DHS datasets to inform a maternal age cohort and a maternal age period, which are then combined to produce results of age-specific mortality [Rajaratnam et al., 2010]. Other methods proposed include the cohort change and birth history imputation [Hill et al., 2015; Brady & Hill, 2017]. These methods assume static fertility and ignore recent mortality experiences. To overcome these challenges, it has been proposed to use a model based on discrete hazards survival analysis, trained using 243 DHS datasets from 76 countries, but this is yet to be applied in mapping neonatal mortality [Burstein et al., 2018].

*Estimation of neonatal mortality by the IHME*

The estimation process had three main components. First, demographic methods were used to analyze empirical data on deaths from, vital registration systems, CBH and SBH [Wang et al., 2014]. Mortality data were synthesized in a process where a non-linear mixed-effects model was applied to examine the relationship between mortality, skilled birth attendance, income per capita, maternal education and death rate from HIV/AIDS. Secondly, a spatiotemporal Gaussian process regression was applied to the residuals of the outputs of the linear model in step one, by borrowing strength in time and from countries within the same GBD group [Wang et al., 2014]. In the last stage, results from the second step were used as priors in a gaussian process regression to generate estimates of mortality. Finally, age models were applied to estimate age-specific mortality rates for neonatal, post neonatal and childhood age groups [Wang et al., 2014].

This process produces national-level estimates of neonatal mortality, but recently, the IHME extended this process to mapping neonatal mortality at 5 by 5 km spatial resolutions in Africa [Golding et al., 2017]. This process involved the assembly of georeferenced SBH and CBH data on childhood and neonatal deaths across the continent. However, in 41% of the datasets, GPS locations were not available, and the team relied on randomly distributing individual mortality data within the administrative unit they fall in. This is a significant limitation of the process, more so for countries like Sudan, Somalia, Botswana which relied on input data from only administrative units rather than point-based. The mapped points (n=65,390) were then matched to several covariates which were to aid estimation of mortality in all the 5 by 5 km pixels covering the continent. These were night-time lights, educational attainment, *Plasmodium falciparum* parasite rate, women fertility, enhanced vegetation index, urban-rural distinction, proportion of land under irrigation and accessibility to cities with more than 50,000 population [Golding et al., 2017].

An ensemble method was then used to select covariates, capture non-linear effects and capture interactions between the covariates. The ensemble model consisted of a generalized additive model, lasso regression, ridge regression and boosted regression trees. Using the selected covariates from the stacked regression approach, a Bayesian geostatistical model was used to estimate the probability of mortality in any pixel while also producing uncertainty intervals using 1000 draws. The model was designed in such a way that it accounted for both spatial and temporal correlation structure. Finally, the pixelated results were aggregated to national levels to calibrate values of mortality using those obtained from the national level GBD estimates [Haidong et al., 2016]. The final results are therefore presented at 5 Km spatial resolution for every year from 2000 to 2015 and can be aggregated to national levels [Golding et al., 2017].

*Estimation of neonatal mortality by the UNIGME*

Similar to the IHME analysis, the UNIGME produces estimates of neonatal mortality rates on an annual basis, based on vital registration and sample systems, population censuses and household surveys. The model is developed in such a way that it is flexible enough to estimate neonatal mortality in a way that the outputs closely follow the original data and are also relatively smooth in countries which have large uncertainties. To do so, the model relies on the relationship between NMR and U5M where an inverse relationship is assumed i.e. under-5 mortality rate decreases with increase in neonatal mortality rate. Country specific effects are also captured to account for the effect of data richness in different countries [Alexander & Alkema, 2016].

The first step is therefore to estimate an appropriate function that describes the ratio of NMR to U5M. The function is estimated by plotting a loess curve through a scatter plot of the ratio of neonatal and non-neonatal deaths versus under-five mortality. The function finds specific intercept and coefficients that suggest that a percent point increase in U5M leads to a 0.65% decrease in neonatal deaths. This function is then applied to country specific estimates of U5M to estimate neonatal mortality. To capture differences of these values in countries and over time, specific country and time effects are added into the model, through B-spline regression models. Results of the UNIGME assessments are also hosted by the UNICEF Equitable strategies save lives tool (EQUIST), https://www.equist.info/en/pages/dashboard, that produces subnational estimates of both MMR and NMR in some countries.

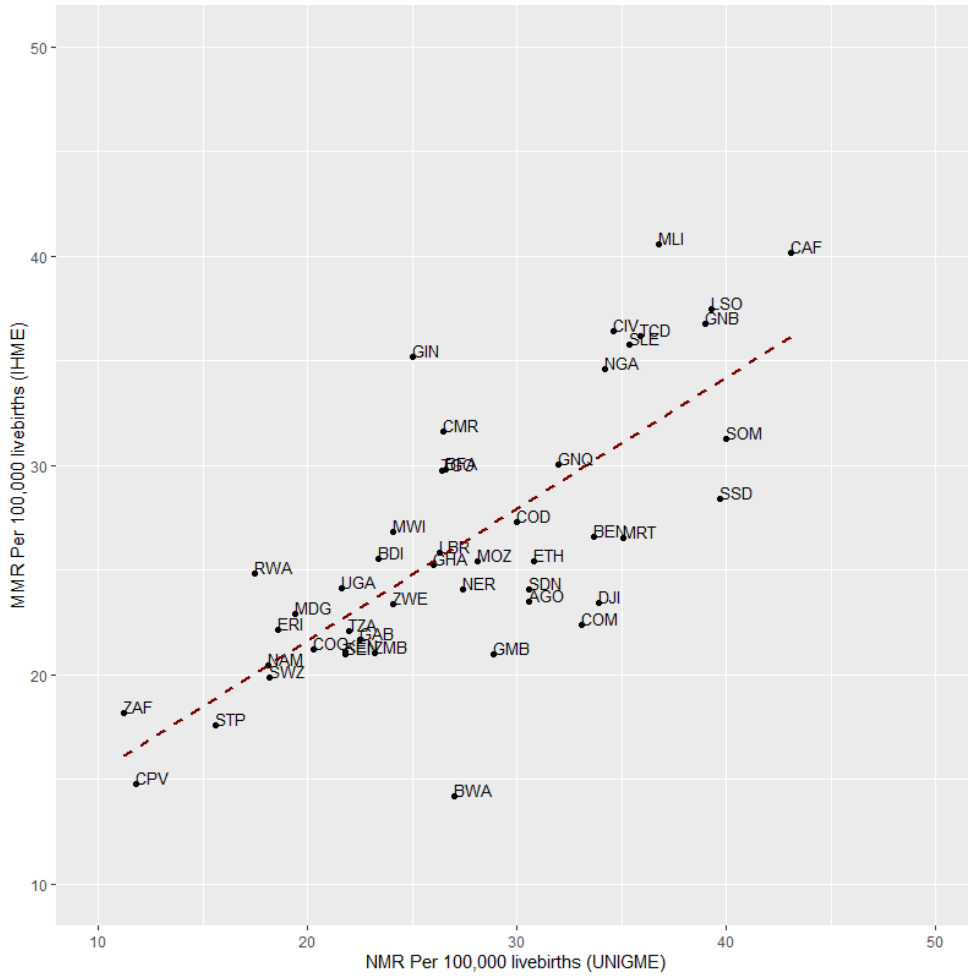
#### 1.6.2.1 The burden of neonatal mortality in sub-Saharan Africa

The differences in methodology, data sources and inputs have been summarized in Table 1.6. The correlation between the two sources was much higher compared to the case of MMR as shown in Figure 1.8. The correlation was 0.75 with major differences in countries such as Botswana and Guinea. Just as was done with MMR, subsequent discussions will focus on the IHME source given its better fit to the original data [Alkema & You, 2012].

Table 1.6 Major differences in methodology and datasets used in modelling neonatal mortality by IHME and UNIGME

| Indicator | IHME | UNIGME |
|---|---|---|
| Number of sources | 652 | 550 |
| Number of countries | 188 | 195 |
| Exclusion criteria | Data during conflict period are excluded | Modified estimation method for countries with conflict data based on expert opinion and intervention data. Essentially changing the smoothing parameter to capture conflict periods |
| Model | Gaussian Process regression | Bayesian hierarchical penalized B-splines regression model |

Figure 1.8 Correlation between NMR from IHME and the UNIGME. Labels are given for the gaul code names

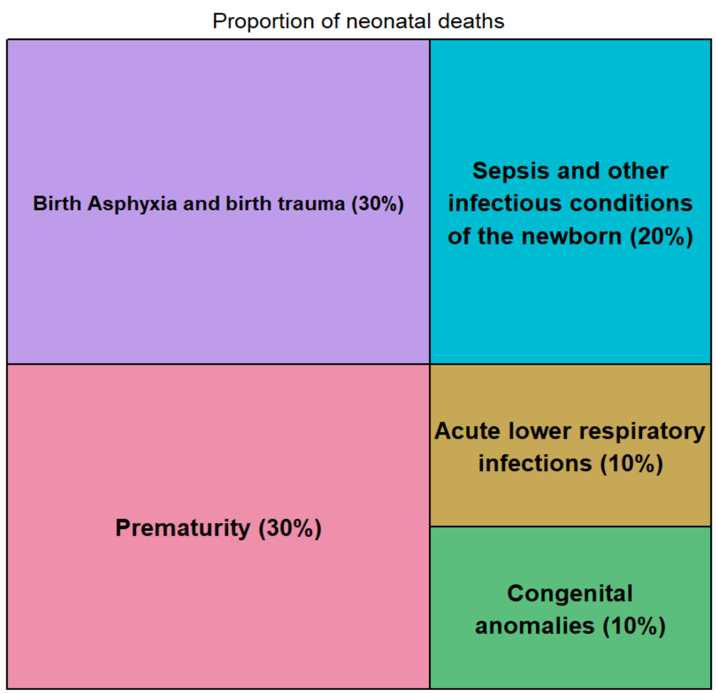



In SSA, approximately 1 million newborns die every year, and this translates to 13,000 deaths per day [Ma et al., 2019]. Substantial variations in neonatal mortality exist within the region, from as low as 14 deaths per 1,000 livebirths in Botswana and Cape Verde to as high as 42 per 1000 livebirths in Central Africa Republic [Hug et al., 2019]. A recent modelled prediction of neonatal mortality at 5x5 km spatial resolution also demonstrated fine-scale variation in neonatal deaths across the continent [Golding et al., 2017]. To achieve a reduction of neonatal mortality to less than 12 per 1,000 livebirths for attainment of the SDGs, an understanding of the causes of these deaths is required.

### 1.6.2.2 Causes of neonatal mortality

For adequate programme design and monitoring, understanding the causes of neonatal death is essential. In 2017, the UNIGME estimated that in SSA, prematurity and birth asphyxia accounted for approximately 60% of the neonatal deaths [GBD, 2017] (Figure 1.7). The other causes were sepsis and other infections, acute lower respiratory infections and congenital anomalies. This section focuses on the causes that require or are likely to progress to a form requiring hospital care.

Figure 1.9 The proportional causes of neonatal mortality in SSA [GBD, 2017].




#### a) Preterm birth

Preterm birth is defined as births occurring before completion of 37 gestational weeks, or less than 259 days from the first day of the last menstrual period [Dbstet, 1977]. Preterm neonates face a great risk of morbidities and complications such as necrotizing enterocolitis, sepsis, hypoxic-ischemic encephalopathy, respiratory distress syndrome and feeding difficulties [Mwaniki et al., 2012; Lawn et al., 2014; Aluvaala et al., 2015b]. Preterm birth can be classified as extreme (less than 28 weeks), very preterm (28 to 32 weeks), moderate (32-34 weeks), and late preterm (34 to < 37 weeks). These can also be extremely low birthweight (<1000g), very low birthweight (<1,500g) and low birthweight (<2,500g). In SSA, nearly three quarters of all the neonatal deaths occur in the first week of life with the highest risk in the 4.2 million births that are pre-term [Chawanpaiboon et al., 2019]. Prevention of neonatal deaths in children born preterm requires a combined health system approach across the different levels of care [Bhutta et al., 2014]. Approximately 70% require quality inpatient and supportive care that should be delivered on time [Wall et al., 2009; Lawn et al., 2013].

**b) Birth Asphyxia**

Birth asphyxia occurs when there is hypoxemia (reduced oxygen) and hypercapnia (accumulation of carbon dioxide) due to an impairment of blood-gas exchange [Aslam et al., 2014]. Continuous asphyxia leads to multiple organ dysfunction and this increases the risk of mortality if adequate care is not provided. Asphyxia occurs due to maternal hemodynamic compromise, placental abruption, umbilical cord knot or compression, uterine conditions or infection. It can occur before birth or immediately after birth [Gillam-Krakauer & Gowen Jr, 2018]. Treatment of respiratory distress, coagulopathy and myocardial dysfunction requires supportive inpatient care. These include intubation, surfactant and oxygen therapy for those with respiratory distress and pulmonary hypertension, prudent use of blood products to treat coagulopathy and vasopressors to manage myocardial dysfunction [Levene, 1993].

**c) Sepsis and other infections**

Neonatal sepsis occurs when a body's response to an infection damages the organs and tissues. Neonatal sepsis manifests itself in several signs and symptoms including fever, hypothermia, respiratory distress, feeding difficulties, lethargy, hypotonia, seizures, bulging fontanel, poor perfusion, bleeding problems and more importantly a "*Just not looking right*" [Gerdes, 1991]. Early recognition and detection of bacterial infection are essential in treating neonatal sepsis. A recent multi-country assessment of potential solutions found that treatment of neonatal sepsis requires inpatient hospital care [Moxon et al., 2015], but in situations where referral is not possible, multicenter clinical trials have shown that the use of simplified antibiotic regimens can be effective [Tshefu et al., 2015].

### d) Congenital anomalies

Congenital anomalies refer to structural or functional birth defects that occur during intrauterine life, during or after birth. Although almost half of all congenital anomalies cannot be due to a specific cause, evidence suggests that there are certain environmental and genetic causes that pose as risk factors. Genetic factors can be inherited or from mutations resulting from sudden changes in genes. Consanguinity which occurs when parents are related by blood increases the chances of congenital abnormalities further increasing the risk of neonatal mortality. Ethnicity can also play a critical role in determining the prevalence of congenital anomalies, for example, in some ethnic communities such as Ashkenazi Jews have a high prevalence of genetic mutations such as Hemophilia C [Halevi, 2008]. Low-income status has also been associated with a higher prevalence of congenital anomalies. Approximately 94% of all congenital anomalies are in low- and middle-income countries. Indirectly, mothers in these countries have poorer nutritional statuses, increases exposure to infections and poorer access to healthcare, factors which can increase the possibility of developing congenital anomalies. Maternal infections such as rubella and more recently zika virus have been related to the development of these anomalies [Cauchemez et al., 2016; Yazigi et al., 2017]. Management strategies for the different causes are shown in Table 1.7.

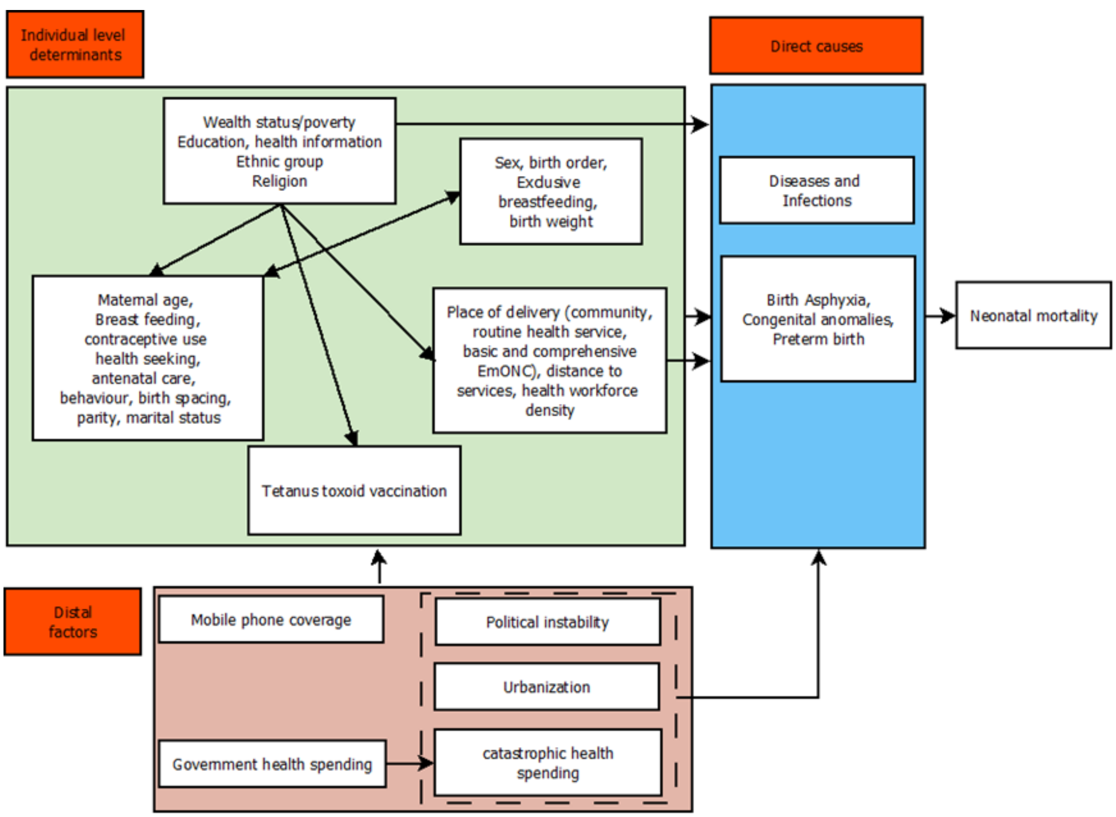
Table 1.7 Newborn complications and their management obtained from [WHO, 2017b]. services in hospitals are shaded in dark orange.

| Complications | Signal Functions |
|---|---|
| Neonatal Sepsis | Prophylactic antibiotics for prevention of sepsis<br>Empirical antibiotics for suspected neonatal sepsis, can be pre-referral<br>Those with critical illness (at presentation or developed during treatment of clinical severe infection) should be hospitalized after pre-referral treatment. |
| Preterm and Low-Birth-Weight Newborn | *Prevention of hypothermia immediately after birth*<br>• Stable neonates, LBW >2000g Kangaroo mother care (KMC)<br>• Stable LBW <2000g intermittent KMC<br>• Unstable neonates <2000g place put in incubator<br>*Oxygen therapy and concentration for preterm newborns*<br>• For preterms < 32 weeks oxygen therapy with 30% oxygen if blended oxygen is not available<br>• Higher concentrations considered for neonates with heart rate of less than 60 beats per minute after 30 seconds<br>*For newborns with respiratory distress syndrome*<br>• Continuous positive airway pressure (CPAP)<br>• Surfactant administration<br>*Feeding of Low-birth-weight (LBW) infants*<br>• Should be fed mother's own milk.<br>• If cant be fed mothers milk then fed donor human milk<br>• Alternatively should be fed standard infant formula or preterm infant formula<br>• VLBW infants should be given vitamin D supplements<br>• Should be given daily calcium |
| Birth Asphyxia | Bag and mask ventilation (BMV) OR<br>Intubation with or without medications at birth |
| Congenital anomalies | Many structural congenital anomalies can be corrected with paediatric surgery and early treatment can be administered to children with functional problems such as thalassaemia (inherited recessive blood disorders), sickle cell disorders, and congenital hypothyroidism (reduced function of the thyroid). |

### 1.6.3 Broader determinants of maternal and neonatal mortality

The determinants of neonatal mortality can be grouped into intrinsic at the individual level and other extrinsic factors which can either affect mortality directly or indirectly. Intrinsic factors include poverty, education, health system capacity including distance to facilities and quality of care, availability of immunisation services overall health-seeking behaviour. These can be related among themselves and affect outcomes in different ways. Extrinsic factors, on the other hand, include factor such as government spending that affects health expenditure or political stability. Socio-economic and environmental factors such as poverty, government health expenditure or urbanisation affect access to health services or quality of these services. For example, increased government health expenditure increases workforce, facilities, geographic access to services or access to contraceptives. Poverty and education also have high correlations, with reducing poverty often highly correlated with increased education. Geographic access is affected by factors such as government health expenditure, poverty or urbanisation. Geographic access to hospital services which provide CEmONC services ensures timely access to obstetric and newborn interventions that significantly reduce the severity of outcomes or mortality. These are conceptualised in detail in Figure 1.10 and described in detail in Table 1.7.

Figure 1.10 Conceptual framework showing the causal pathway between the determinants of neonatal mortality. The arrows point how determinants interrelate based on their location in the pathway. Thus, distal factors affect intermediate factors, which in turn may exacerbate direct determinants. Direct determinants like infections/diseases or conditions can aggravate other direct causes or lead to neonatal death. The conceptual framework is adapted from[Mosley & Chen, 1984]




**Footnote:** BMI; Body mass index, HIV; human immunodeficiency virus, SBA; skilled birth attendance, ANC; antenatal care attendance.

Table 1.8 Determinants of maternal and neonatal mortality, including their expected relationship. The rationale for choosing these factors is also shown and described using sample references.

| | Indicator | Rationale |
|---|---|---|
| **Intrinsic factors** | | |
| 1 | Education | Increasing educational levels are likely to boost capacity of women to obtain, process and comprehend the benefits of good maternal services such as antenatal care, reproductive health and use of contraceptives. The relationship between maternal or neonatal deaths and education may also be indirect, through increased self-esteem and empowerment to make health related decisions [Shen & Williamson, 1999; Evjen-Olsen et al., 2008; Alvarez et al., 2009; Karlsen et al., 2011]. Its influence can also override other factors like distance to facilities. |
| 2 | Fertility rates, parity | The risk of maternal and neonatal mortality is highest for first pregnancies and fifth and subsequent ones. Adolescent mothers are more likely to be primiparous and thus adolescent fertility can also be a risk factor in this age group than in older women. This relationship may, however, be significantly affected by differences in access to services, poverty, and prevalence of infectious disease cofactors which may increase the risk [Nove et al., 2014; Girum & Wasie, 2017]. Similarly, nulliparous women especially those below 18 years of age have the highest risk of neonatal mortality [Kozuki et al., 2013]. |
| 3 | Prevalence of contraceptive use | Family planning through contraceptive use is known to have non-contraceptive benefits in women through the promotion of birth spacing and control on the number of children one can have. Adequate birth spacing and reduced number of children reduces exposure to pregnancy-related risks of deaths [Ahmed et al., 2012]. |
| 4 | Obesity, nutritional factors and maternal height | Maternal nutrition affects maternal and newborn survival outcomes in two different ways; anaemia (demand of fetus for iron) and folate deficiency. Obese women are more likely to die during childbirth because of increased risk due to comorbid conditions such as diabetes, cardiac problems and hypertension [Di Cesare et al., 2016; Abarca-Gómez et al., 2017; Daru et al., 2018]. Short maternal height also increases the risk of neonatal mortality [Arendt et al., 2018] |
| 5 | Health workforce | Shortages in the health workforce can mean interventions may be omitted or incorrect treatments administered further exacerbating maternal and newborn complications and increasing chances of maternal and neonatal deaths [Homer et al., 2014; Holmer et al., 2015]. Different cadres of skilled workforce can be considered. |
| 6 | Skilled birth attendance | Most obstetric complications can be prevented with access to a skilled birth attendant (doctors, nurses, midwives) during and immediately after childbirth. Skilled birth attendance ensures that the risks posed to a mother and child during labour or post-partum are adequately identified and whenever possible prevented [Kassebaum et al., 2016; Amouzou et al., 2017]. |
| 7 | Antenatal care attendance | Timely and appropriate ANC provides opportunities for detection of obstetric complications, provision of intermittent preventive treatment for malaria during pregnancy (IPTp), tetanus toxoid immunization, and identification and management of infections including HIV, and other sexually transmitted infections. ANC attendance also provides an opportunity for promotion of healthy behaviours such as planning for optimal pregnancy spacing which can reduce the risk of mortality [Conde-Agudelo et al., 2007; Arunda et al., 2017; Roy & Haque, 2018]. |
| 8 | Early initiation of breastfeeding | Initiation of breastfeeding within the first hour of life reduces the risk of neonatal deaths [Debes et al., 2013]. |

Table 1.8 continued…

| | Indicator | Rationale |
|---|---|---|
| 9 | Access to drinking water and sanitation | Availability of safe drinking-water (defined as a water source that is free of contamination) and to adequate sanitation (toilets and improved latrines that prevent people from encountering human waste) is essential for good health. Poor access to clean water and sanitation makes mothers more susceptible to infections which can increase risk of mortality [Ahmed et al., 2012; Benova et al., 2014; Campbell et al., 2015]. |
| 10 | Poverty | There are multiple mechanisms through which poverty influences health; First is directly by affecting the ability to obtain services, where the poor cannot afford to pay for healthcare and are unable to cater for costs required to access care. Besides, poor countries face the challenge of meeting the demand for adequate services such as antenatal care and skilled birth. Second is through indirect pathways, where the lack of enough information on health-promoting practices further inhibiting their ability to obtain care [Castro-Leal et al., 2000]. It is for these reasons that poverty is expected to increase the risk of maternal mortality. Ability to pay can also override other factors like distance to facilities. |
| | **Extrinsic factors** | |
| 11 | Catastrophic expenditure for health care | Difficulty in paying for health services including non-medical costs such as transport, lodging and food can impede obtaining services. This is known as catastrophic health expenditure [Xu et al., 2003; Shrime et al., 2015; Ezat et al., 2017]. |
| 12 | Current health expenditure (% of GDP) | Maternal and newborn interventions can be very costly, as they involve a well-functioning and organized multidisciplinary team that occurs throughout the spectrum of a functional referral system. Health expenditures can cover a range of maternal health services such as family planning, abortion care, obstetric care and can even extend to transport services during delivery. Therefore, increased health expenditure can lead to an increased availability of quality health services [Alvarez et al., 2009; Graham et al., 2016]. |
| 13 | Urbanization | Urbanization can influence access to maternal and newborn services in both ways.<br>Slum-dwellers who make up about one-third of the continents' total population, face poor health outcomes compared to residents of other urban areas or even rural areas. Women living in urban slums of Africa encounter several of obstacles in accessing maternal services such as cost of services, distance to care and lack of transportation and poor quality of care. These factors impede access to crucial maternal services and therefore increased maternal mortality rates [UN-Habitat, 2004; Ziraba et al., 2009; Izugbara & Ngilangwa, 2010; Emina et al., 2011; Shetty, 2011; Kruk et al., 2016b]. |
| 14 | Mobile cellular subscriptions (per 100 people) | The penetration of mobile telephony provides health workers and health systems access to populations that have traditionally been difficult to reach. Access to mobile phone services has a wider benefit of improving access to maternal services through easier acquisitions of transport means and mobile money transfers. |
| 15 | Access to drinking water and sanitation | Poor access to clean water and sanitation makes mothers more susceptible to infections which can increase risk of both maternal and neonatal mortality [Ahmed et al., 2012; Benova et al., 2014; Campbell et al., 2015]. |
| 16 | Fragility and political stability | Violence can disrupt the utilization of key interventions. Travel costs are also expected to increase as the flow of medical supplies and personnel is disrupted [Price & Bohara, 2013]. Increased fragility is expected to increase the risk of maternal deaths, while may also make geographic access poor [Murray et al., 2002]. |

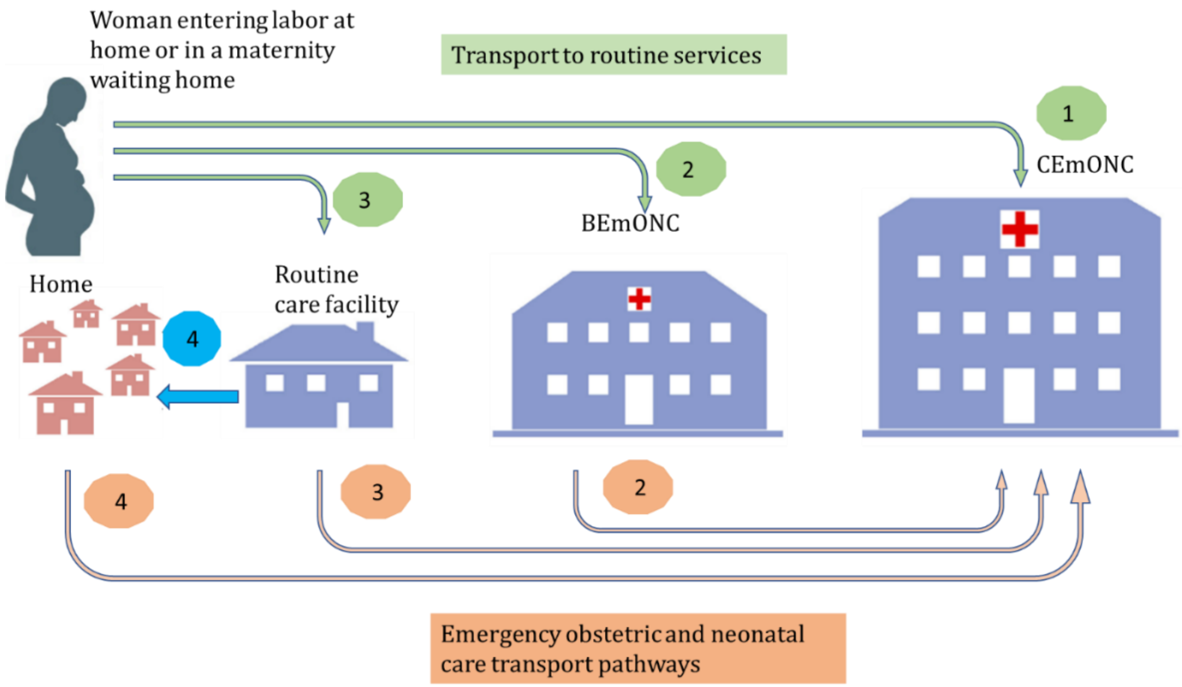
### 1.6.4 Where interventions to reduce maternal and neonatal deaths can be obtained

Maternal and newborn services can be provided at different levels of care depending on the complexity. Ensuring geographic access to emergency obstetrics is therefore important in averting a significant proportion of maternal and neonatal deaths. The concept of maternal and neonatal service delivery presents an organised framework for delivering evidence-based clinical services aimed at reducing maternal and neonatal mortality [WHO et al., 2009]. Based on numerous studies [Hofmeyr et al., 2009; Van Lonkhuijzen et al., 2010; Hussein et al., 2012], these services can be provided along a continuum of care ranging from the community levels to referral hospitals.

### 1.6.5 Cascade of maternal and newborn care service delivery

To effectively address the challenges of EmONC, an understanding of the different components that affect access to facilities able to handle maternal and neonatal conditions is needed [Kobusingye et al., 2006]. The obstetric and neonatal emergency care continuum can be conceptualised in three main domains: the community level, routine health services and emergency obstetric service providers [Campbell et al., 2016]. The interrelationships between these three components which define place of birth and the endpoint women in childbirth take in a given context is shown in Figure 1.11 and described in detail in Table 1.9.

Figure 1.11 Framework of pathways required for adequate childbirth care. It outlines the different stages a mother or newborn can take from the home to any health service provider and the different pathways are described in Table 1.9 [Campbell et al., 2016].




### 1.6.5.1 Community-based systems

The first responders are the community-based health systems who seek to create emergency care awareness at the community level (Figure 1.11). Community-based health systems play an important role in improving access to health services, by accessing patients who cannot receive care at higher levels of care [Bhutta et al., 2014]. Reviews assessing the effectiveness of community based interventions have shown they reduce maternal mortality by 28% [Kidney et al., 2009] and neonatal mortality by 26% [Lassi et al., 2015]. Most of these effects are due to improvements in household behaviour practices such as improved hygiene in the pre and postpartum period and improved health care utilisation [Bhutta et al., 2014]. Community-based health services can be provided by two main cadres. Community health workers who are trained to help communities recognise maternal and newborn danger signs in addition to treating uncomplicated diseases such as diarrhoea and respiratory infections.

Table 1.9 Conceptual framework of pathways to adequate childbirth care. It shows the interrelationships between place of birth and the endpoint of the paths women take in a given context [Campbell et al., 2016]. The colours for each row and column correspond to those in Figure 1.11 above. The green and orange refer to transport services where geographic access can have an influence when seeking care, while the grey areas correspond to service provision once at the facility.

| | **Transport at start of labour** | **Provision of quality care for routine childbirth** | **Emergency transport for complications** | **Provision of quality care for complications (EmONC)** |
|---|---|---|---|---|
| Skilled Birth Attendant delivery | Woman/family decision maker:<br><br>• Decides on intended place of childbirth<br><br>• Has ability to reach intended location, (transport, communication and cost) | Facility has adequate:<br>• Staff cadres and skills for routine childbirth<br>• Staff numbers<br>• Equipment, drugs, and supplies<br>• 24/7 opening times and basic infrastructure | Attendant:<br>• Recognizes need for emergency care<br>• Can identify and reach CEmONC facility (e.g., using emergency medical service) | Facility has adequate:<br>• Staff cadres and skills to manage complications<br>• Staff numbers<br>• Equipment, drugs, and supplies<br>• Blood supply<br>• 24/7 opening times and basic infrastructure |
| Facility with routine care & CEmONC 1 | Woman/newborn travels from home/ MH to CEmOC facility | Uncomplicated childbirth at CEmONC facility or child born without complications | Travel not required; if in mid-wife unit, move to emergency care located on the same sit | Complicated childbirth managed at CEmONC facility |
| Facility with routine care and BEmOC 2 | Woman travels from home or MH to BEmOC facility | Uncomplicated childbirth at BEmONC facility | Woman or newborn who cannot be managed at BEmONC facility travels to CEmONC facility. | 2 |
| Facility with routine care only 3 | Woman travels from home or MH to routine-only facility | Uncomplicated childbirth at routine-only facility | Woman and/or newborn travel from routine only facility to CEmONC facility | 3<br>4 |
| Home with SBA 4 | CHW travels to woman's home | Uncomplicated childbirth at home | Woman travels from home to CEmONC facility | |

**Footnote:** MH stands for Maternity home; CHW – community health workers; SBA – Skilled birth Attendance

The second cadre is the traditional birth attendants who may not be trained in clean delivery but are often encouraged to accompany mothers when they are visiting facilities [Lee et al., 2011]. These two cadres offer antenatal and postnatal services, which complement routine care at the facilities [Lassi et al., 2015]. Nonetheless, community-based systems are only fully beneficial if they are linked to the health service providers, especially in scenarios where a higher level of care is needed [Darmstadt et al., 2014; Lawn et al., 2014; Mason et al., 2014]. Thus, mothers in need of emergency obstetric care are often referred to higher-level inpatient services as shown in Figure 1.11 and described in Table 1.9.

#### 1.6.5.2 Routine service providers

At the second level are the tier 2 health service providers who provide routine maternal and newborn services such as family planning, administration of uterotonics, partograph and infection prevention. For the newborn, services include immediate drying and simulation, bag and valve mask ventilation, provision of warmth, hygienic care, administration of Vitamin K and support for immediate breastfeeding. These are typically provided at dispensaries, health posts and smaller health centres [Campbell et al., 2016]. It is often determined by the ability to obtain services from a skilled birth attendant (nurse, midwife or any other skilled attendant), in an enabling environment [Koblinsky et al., 2016; Miller et al., 2016].

The importance of routine services in reducing maternal and neonatal mortality has been widely documented. For example, cleansing of the umbilical cord with antiseptic has been associated with a reduced risk of neonatal mortality by 23% [Imdad A & Bhutta, 2013], while early initiation of breastfeeding can reduce neonatal mortality by 44% [Debes et al., 2013]. This shows that overall, facility health workers play a critical role in providing early education and counselling needed for adequate care of newborns and this can go a long way to reducing neonatal mortality.

Access to routine services such as family planning and antenatal care have been associated with reductions in maternal mortality at various proportions [Chola et al., 2015]. In addition, prevention of bacterial infections during childbirth can reduce maternal deaths by 10% [Bonet et al., 2015]. Routine service providers also enable adequate communication and transport mechanisms to the emergency obstetric service for conditions that are life-threatening [Campbell et al., 2016].

### 1.6.5.3 Emergency obstetric care

Approximately 15% of all pregnancies experience potentially life-threatening complications and require emergency obstetric care [WHO et al., 2009]. Facilities able to offer emergency obstetric care (EmOC) are defined by a shortlist of key life-saving obstetric interventions. In 1986, the *Essential Obstetric Functions at First Referral Level* was published by the World Health Organisation (WHO) and aimed to describe the key functions that hospitals should provide. These included the treatment of complications (caesarean delivery, anaesthesia, blood replacement, manual procedures) in addition to monitoring functions (partograph), a preventive function (which promotes family planning) and an emergency newborn function (neonatal resuscitation) [WHO, 1991].

In 1997, the UN guidelines described the eight EmOC signal functions aimed at treating the five main causes of maternal mortality (sepsis, obstructed labour, haemorrhage, hypertensive diseases, obstructed labour and unsafe abortion) [UNICEF, WHO, UNFPA, 1997]. EmOC was partitioned into either basic or comprehensive EmOC, with the former comprising six medical functions (parenteral anticonvulsants, parenteral antibiotics, manual removal of placenta, parenteral oxytocic drugs, removal of retained products, and assisted vaginal delivery) and the latter adding caesarean section and blood transfusion to the basic services to form comprehensive emergency obstetric care (CEmOC) services. Health centres should essentially provide basic emergency obstetric care (BEmOC) services, while hospitals are expected to provide CEmOC services [WHO et al., 2009].

### 1.6.5.4 Inpatient newborn care

Many babies born with low birthweight especially preterm and those born small for their gestational age, require inpatient care to support their feeding and maintain body temperature. Preterm babies also face increased risk of infections, jaundice and respiratory problems thus elevating their risk of mortality [WHO, 2017b]. Similar to emergency obstetric care, attempts have been made to develop recommendations for selecting facilities able to offer inpatient newborn care [Ntoburi et al., 2010; Gabrysch et al., 2012; Moxon et al., 2015]. Although these recommendations vary, common features include; feeding support with nasogastric tubes and intravenous fluids; neonatal resuscitation with bag and mask, infection prevention and control, including antibiotics; oxygen provision and to a lesser extent continuous positive airway pressure; and phototherapy for jaundice [Ntoburi et al., 2010; Gabrysch et al., 2012; Moxon et al., 2015].

The previous section highlights the importance of inpatient care, in managing maternal and neonatal deaths. A significant proportion of these deaths can be managed at hospitals levels, which are vital components of health systems given their ability to handle patients with varying acute, emergency and convalescent conditions [Hamel & Janssen, 1988; van Lerberghe et al., 1997; WHO, 2017c]. In most cases, hospitals are organised hierarchically, with those providing basic inpatient care at the first level of referral (district hospital) and advanced care at regional or national hospitals (Table 1.10) [McCord et al., 2015].

Table 1.10 Levels of hospital care and general services they offer [McCord et al., 2015]

| **Level of care** | **Services** | **Alternative terms** |
|---|---|---|
| First level hospitals | Internal medicine, gynaecology & obstetrics; 50-250 inpatient beds, limited laboratory services | Primary hospitals |
| | | District hospitals |
| | | Rural hospitals |
| | | Community hospitals |
| | | General hospitals |
| Second level | Service is highly specialized and receives referrals from several district hospitals | Provincial hospitals |
| | | Regional referral hospital |
| | | |
| Third level | Highly specialized services such as; cardiology, imaging units; have teaching units and 300-1500 beds | National hospitals |
| | | University & teaching hospitals |
| | | Central hospital |

District hospitals are particularly important as they offer the first level referral services. The WHO defined these hospitals as capable of providing services relating to: internal medicine, obstetrics and gynaecology, mental health, eye care, surgery, trauma and orthopaedics, 24 hours a day [WHO, 1992]. In addition, a typical district hospital has 50-200 inpatient beds, functional laboratory and blood bank services and at least three doctors providing inpatient care [Hamel & Janssen, 1988; van Lerberghe et al., 1997; McCord et al., 2015]. These hospitals, therefore, form the first point of health delivery systems where emergency/acute conditions can be handled [English et al., 2006]. In addition, they offer services at the lowest health administrative units (the district), thus playing an important role in expanding access to emergency services.

All SSA countries have established health sector strategic plans (HSSPs), the cornerstone policy documents that set out the plans and visions for the development of the health sector. The HSSP lays out the status of healthcare in a country, sets out a framework for achieving specific health targets and defines processes for monitoring progress [WHO, 2017d]. HSSPs are therefore the best available documents for assessing service provision at different levels. Strong HSSPs will be critical in the delivery of resilient health systems and attainment of UHC. The next section presents a review of HSSPs to assess their prioritisation of CEmONC services at district hospitals, including the populations they are supposed to serve.

### 1.6.6 Hospital services in sub-Saharan Africa

The most recent HSSPs were retrieved in April 2017 from the ministry of health websites. For those not available from ministry websites, the WHO country planning website was used as an alternative [WHO, 2017d]. For the United Republic of Tanzania, two HSSPs were found, one each for Zanzibar and mainland Tanzania and their results are presented separately. In Somalia 3 HSSPs were available, one each for Puntland, Somalia and Somaliland regions, but these were not any different and were presented as one. The results of the HSSPs reviewed including the minimum essential services at first level referral hospitals and catchment population per country are shown in Table 1.11.

Table 1.11 Sources of data on catchment populations served by primary hospitals and the minimum essential services the first level referral hospitals provide.

| Country | Source [Reference in Appendix 1] | Catchment population for first level referral hospitals | Specific minimum essential services |
|---|---|---|---|
| Angola | [2,147] | 150,000 - 500,000 | Laboratory, in-patient care, radiology |
| Benin | [5] | NR | NR |
| Botswana | [8,148] | NR | Obstetrics, gynaecology, psychiatric care, oncology |
| Burkina Faso | [10,149] | NR | Surgery, appendicitis |
| Burundi | [13] | NR | NR |
| Cameroon | [16] | NR | NR |
| Cape Verde | [19] | NR | NR |
| CAR | [22] | NR | NR |
| Chad | [24] | NR | Surgery, obstetrics, medicine |
| Comoros | [28] | NR | NR |
| Congo | [30] | NR | Surgery, obstetrics, paediatrics, medicine |
| Cote d'Ivoire | [32] | NR | NR |
| DRC | [35] | 100,000-200,000 | Surgery, obstetrics, paediatrics, medicine, gynaecology |
| Djibouti | [39] | NR | NR |
| Equatorial Guinea | NR | NR | NR |
| Eritrea | [42] | 50,000-100,000 | Surgery, obstetrics |
| Ethiopia | [44,151] | 60,000-100,000 | Surgery, blood transfusion |
| Gabon | [49] | NR | NR |
| Gambia | [52] | | Surgery, obstetrics, blood transfusion |
| Ghana | [55,151] | 100,000–200,000 | Surgery, obstetrics, gynaecology, child health, medicine, anaesthesia, accident, emergency services |
| Guinea | [57] | Prefecture population | Surgery, obstetrics, paediatrics, medicine, gynaecology |
| Guinea Bissau | [60] | NR | NR |
| Kenya | [62,152] | 100,000 | Surgery, inpatient care, blood transfusion, laboratory, consultative services |
| Lesotho | [67] | District population | Specialized services, laboratory services |
| Liberia | [70] | 200,000 | Surgery, obstetrics, paediatrics, general medicine, gynaecology |
| Madagascar | [73] | District population | Surgery, obstetrics, paediatrics, medicine, neonatal care |
| Malawi | [76] | District population | Surgery, trauma care |
| Mali | [81] | 250,000 | NR |
| Mauritania | [84] | NR | NR |
| Mauritius | | NR | NR |
| Mozambique | [86] | 50,000-250,000 | Surgery, radiology, emergency services |
| Namibia | [90,153] | NR | Surgery, obstetrics |

Table 1.11 continued…

| **Country** | **Source [Reference in Appendix 1]** | **Catchment population for first level referral hospitals** | **Specific minimum essential services** |
|---|---|---|---|
| Niger | [94,154] | District population | Inpatient services, caesarean sections |
| Nigeria | [97] | NR | Surgery, obstetrics, gynaecology, paediatrics |
| Rwanda | [99,155] | District population | Surgery, obstetrics, gynaecology, inpatient/outpatient services, laboratory, radiology |
| Senegal | [104] | NR | Surgery, general medicine |
| Seychelles | | NR | NR |
| Sierra Leone | [106] | NR | Inpatient and diagnostic services, management of accidents, emergencies |
| Somalia | [109,110,111] | NR | NR |
| South Africa | [116] | NR | Surgery, obstetrics and gynaecology, paediatrics, trauma care, family medicine, radiology, anaesthetics |
| South Sudan | [118] | 300,000 | Surgery, obstetrics, paediatrics, medicine |
| | | | |
| ST&P | [102] | NR | |
| Sudan | [120] | NR | NR |
| Swaziland | [122] | NR | Surgery, ear, nose and throat, ophthalmology, dentistry, intensive care, radiology, pathology |
| Tanzania (Mainland) | [124,156] | 250,000 | Surgery, Medicine |
| Togo | [126] | NR | NR |
| Uganda | [132,157] | 100,000-500,000 | Surgery, obstetrics and gynaecology, internal medicine, paediatrics, family medicine, X-ray |
| Zambia | [136] | 80,000-200,000 | Surgery, obstetrics, internal medicine and diagnostic services |
| Zanzibar | [138,158] | District population | Surgery, obstetrics, laboratory testing, radiology |
| Zimbabwe | [141] | 140,000 | Comprehensive preventive, curative services |

Footnote: CAR; Central African Republic, DRC; Democratic Republic of Congo, ST&P; São Tomé and Príncipe. Reunion island is not presented as it is a French department. NR; No record

A total of 50 HSSPs were reviewed, with none located for Equatorial Guinea (Table 1.11). Of these, 27 were in English, 18 in French and 3 in Portuguese. Google translate was used to convert the 21 documents in French and Portuguese to English while acknowledging that this may not be an accurate translation process. District hospitals were identified as the lowest level of hospital care provided, but there were a few exceptions. In Malawi, rural/community hospitals are defined as those offering only primary level services and these were not included as the district hospitals. In Mali, the first level of referral services is offered at Centre de Santé de Référence (CSREF, Referral Health Centre) and these were recorded as district hospitals. In Gabon, Centres Médicaux are the first reference hospitals. Finally, in Burkina Faso, Centre Medical Avec Antenne Chirurgicale are the first levels where emergency care is offered. The focus of this section was to extract minimum essential obstetric services and a metric of access to these facilities.

### 1.6.7 Essential services at district hospitals

The HSSPs should ideally capture adequate information on definitions of hospital services, minimum clinical and laboratory equipment, and staffing needs. Of the 50 HSSPs reviewed, 31 mapped out the services expected to be available at district hospitals [Table 1.11]. These hospitals should, in theory, offer services covering; surgery, paediatrics, obstetrics, gynaecology, blood transfusion and radiological services. Surgical capacity is the most commonly referenced essential service at district hospitals with 80% (25/31) of the HSSPs recognising it. 61% (19/31) of the HSSPs identify gynaecology and general obstetrics as an essential service although some obstetric services like caesarean sections may have already been captured in surgery. Other services are; inpatient care (n=4), blood transfusion and radiological services (n=3) and anaesthesia (n=2).

As highlighted by this review, health policy for promotion of CEmONC remains basic, with inadequate definitions of minimum essential services that should constitute this higher level of the health sector. For example, obstetrics is a broad term that encompasses various procedures that can be performed in emergency childbirth cases, and none of the HSSPs mentioned the importance of district hospitals providing the full range of eight obstetric signal functions. In addition, some obstetric services should ideally be available at health centres [WHO et al., 2009], and it is important to distinguish the specialities in district hospitals. There was no specific mention of the required neonatal services (only Madagascar had a specific identification of neonatal care as a critical service in district hospitals). Compared to emergency obstetrics (caesarean section and blood transfusion), there are still no universally agreed minimum essential neonatal services that should be available at district hospitals.

### 1.6.8 Population covered by hospitals

None of the HSSPs described a specific distance or time threshold needed for estimating access to hospital care. The definition of access using facility to population ratio varied between the countries, ranging from 50,000 in Eritrea and Mozambique to 500,000 in Angola and Uganda. In other countries such as Guinea, Lesotho, Madagascar, Malawi, Niger, Rwanda and Zanzibar catchment areas are defined as the specific districts (Table 1.11). This creates a need for a more nuanced analyses of access using standardised metrics that account for the heterogenous distribution of both population and facilities, while allowing for comparability of accessibility between countries. The next section therefore introduces the different dimensions of access and will also provide an in-depth exploration of what geographic access is.

## 1.7 Geographic accessibility to CEmONC services

Recommendations have been made for reducing deaths due to maternal and neonatal conditions. The WHO proposes a set of six core indicators, one of which emphasizes adequate geographic distribution of emergency obstetric services. This proposes that there should be at least one CEmONC hospital for every 500,000 population, but given the challenges of facility to population ratios in Section 1.7.1, an additional recommendation is that expectant women be located within 2 hours of a CEmONC hospital [WHO et al., 2009]. In 2015, the Lancet Commission on Global

Surgery also proposed six key indicators for driving the surgical care agenda, and this included ensuring that by 2030, 80% of the population were within 2 hours of a facility that can perform bellwether surgical procedures which includes caesarean delivery [Meara et al., 2015].

Subsequently, the two hour time window has been used to measure spatial access to safe surgery in Zambia [Esquivel et al., 2016], Ghana [Stewart et al., 2016] and a host of other SSA countries [Knowlton et al., 2017a]. Other studies have used the 2-hour window for defining geographic access to CEmONC services [Bailey et al., 2011; Chen et al., 2017; Chowdhury et al., 2017; Ebener et al., 2019], mainly because it roughly defines the period between onset of bleeding and mortality if interventions are not provided. Even though treatment of all the CEmONC conditions may require treatment seeking within shorter or longer time periods, the choice of 2-hour period provides a policy relevant target timeframe for which tracking of population level accessibility can be done. As of May 2019, Ethiopia [MoH Ethiopia, 2018], Rwanda [MoH Rwanda, 2018], Tanzania [MoH Tanzania, 2018] and Zambia [MoH Zambia, 2017] have adopted the 2-hour threshold as a metric for monitoring geographic access in their national surgical obstetric and anaesthesia plans.

With the choice of this time threshold, the outstanding question is therefore to accurately capture populations marginalised from hospital services. Access can be defined using different methods as shown in Section 1.6.1, but accurately defining timely access is dependent on several factors: transport availability, transport speeds assigned to the roads, accuracy of population settlement data, the method of analysis i.e. raster or vector-based, and the resolution of analysis and the data sets fed into the model.

Based on these factors, the next section presents a critical review of studies that have defined geographic access to CEmONC services, to provide an understanding of how accessibility models have been parameterised. The crux of this exercise is to identify gaps in previous studies, and this can inform better analytics of geographic accessibility.

### 1.7.1 Methods of measuring geographic accessibility

#### a) Facility-to-population ratio

This is the simplest method and involves calculating the ratio of providers per population [Neutens, 2015]. It does not necessarily require Geographic Information Systems (GIS) skills and accessibility indices are computed at defined administrative units. This method can be useful in highlighting differences between administrative boundaries with the subsequent identification of gaps in service provision [WHO, 2010b]. Due to its simplicity and ease of interpretation its application has been mainly in policy formulations. Its major limitation is that the travel impedances (elevation, transport availability and distance) encountered when accessing health facilities are not accounted for [Neutens, 2015].

#### b) Euclidean distance

The Euclidean method, which is the simplest distance method, assumes a straight line travel from points of residence to the health service provider locations [Guagliardo, 2004; Noor et al., 2009]. It is also a simple technique that involves defining service availability regions based on a radius of influence. The method is especially useful when specific recommendations on threshold distance exist. For example, 5 Km is commonly used as an indicator of geographic access to primary health facilities. This method however assumes that travel to a health facility occurs in a straight line and may be a poor measure given the influence of transport services on accessibility [Guagliardo, 2004; Neutens, 2015].

#### c) Gravity models

The limitations of the facility to population ratio and Euclidean distance methods resulted in the development of the gravity methods [Luo, 2004], which have evolved from simply defining two-step floating catchment area to the more sophisticated Modified two step floating catchment area method [Delamater, 2013; Ni et al., 2015]. Generally, the gravity model is a combination of availability and accessibility across defined spatial units and was primarily developed from social physics. One of its major advantages is it controls for "capacity" of a facility, competition between facilities and ability to estimate gravity values using numerous ways [Neutens, 2015]. The incremental developments in the model has seen it evolve from simply using the supply and demand data to the inclusion of distance decay effects, multiple transport models and variable incorporation of catchment areas [McGrail & Humphreys, 2009; Wan et al., 2012; Hu et al., 2013; Mao & Nekorchuk, 2013; Vora et al., 2015] in the modified two step floating catchment area method. Despite these numerous advantages, limitations still exist to the model, mainly being its static nature and inability to allow for time varying relationships. Secondly, demand is normally defined at specific spatial units and the model would be affected by the Modified Areal Unit Problem (MAUP), a source of spatial bias which results from aggregation of data. Its accuracy is therefore dependent on ability to define population at fine geographic units and have data on service provider capacity. It is therefore not suited for use in resource limited settings where populations are normally defined at large spatial units.

**d) Kernel density method**

The kernel density model is a variant of the gravity model, which operates by distributing a discrete point value in a surface that is continuous [Schuurman et al., 2010]. Kernel density is a non-parametric way of representing the distribution of a variable. With regards to health service provision, a kernel density around a health service provider represents a 'sphere of influence' whose radius is the bandwidth of the kernel density.

This method, however, has serious methodological and conceptual shortcomings. First, it uses straight line distances completely ignoring the road network. This is far from the reality, as in many cases, road networks affect ability to access a health facility. Secondly, arbitrariness in choosing the kernel density in most cases leads to service densities that spill over from the study area [Guagliardo, 2004]. Thirdly, when modelling the population distribution, the method assumes a smooth distribution from a centroid with density decreasing as distance from the centroid increases, an assumption which is not realistic [Schuurman et al., 2010].

#### e) Network Analysis

Network analysis uses the actual transport routes to model accessibility [Noor et al., 2006; Owen et al., 2010; Masoodi & Rahimzadeh, 2015]. Superiority of the network analysis over Euclidean has already been demonstrated [Tansley et al., 2015], although in low income countries, where most of the populations are rural its usefulness may be diminished [Nesbitt et al., 2014]. In modelling accessibility, the algorithm assumes the use of the nearest facility and travel can only occur along the roads. It is a more computationally intensive method which relies on the ability to define population locations (nodes), accurate transport infrastructure and the routes likely to be used. Although it's a more realistic method its usability in more rural areas may be affected by the fact that transport does not always follow road network [Nesbitt et al., 2014]. Accurate data on transportation routes and populated locations is also difficult to obtain.

#### f) Cost distance analysis

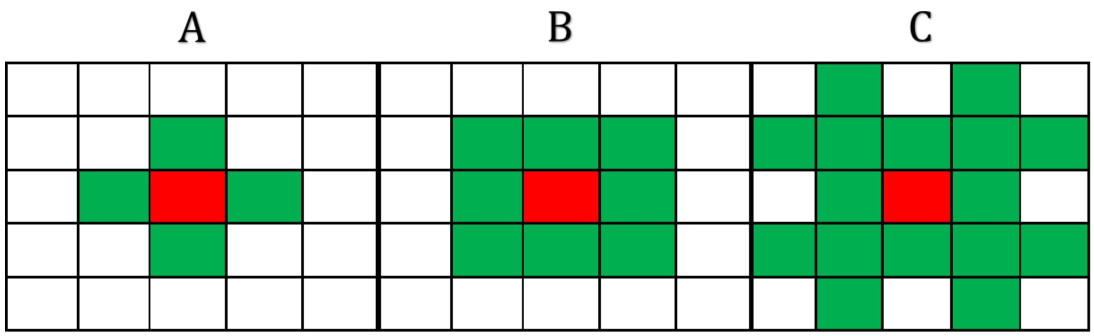
The final method is travel times to health facilities, which provides a more intuitive method of defining accessibility for policy makers [Guagliardo, 2004; Noor et al., 2006; Neutens, 2015]. In this method, distance analyses are conducted using either cost friction values, or using resistance surfaces [van Etten, 2017], in combination with location of health facilities to come up with a surface showing the least time needed to get to the nearest health facility from every populated location [Huerta & Källestål, 2012]. The cost in this method does not necessarily imply financial cost but some composite measure that varies in space. In most cases, this composite measure involves the combination of land use surfaces, elevation and barriers to travel such as water bodies and parks in addition to distances. Thus, in its simplest form, where only distances are used, then the cost distance analysis mimics the Euclidean distance.

Cost distance analyses have been noted to be much more realistic representations of access as people relate more to time taken to get to a health facility than to distances. The availability of datasets that can be used to define travel times, makes it a more attractive choice of defining accessibility. Limitations of this method, include the assumption that individuals use the nearest facility and its inability to account for competition [Neutens, 2015]. In addition, its accuracy is dependent on the spatial resolution used. Its use has therefore gained significant attention, with the development of the AccessMod module for measuring physical accessibility, by the WHO [Ray et al., 2008; Ebener et al., 2019].

### 1.7.2 Distance and route calculations in raster analyses

Distance and route calculations rely on graph theory. This means that rasters are converted to matrices/graphs where the cell centres are nodes which connect to each other. Connection of different nodes defines a neighbourhood structure and are commonly implemented in three different ways. **The von Neumann neighbourhood** - Nodes/cells can be connected orthogonally to the four immediate neighbours as shown in Figure 1.12A. **The Moore neighbourhood –** Neighbourhood is when resulting graph is called the king's graph because it shows all the legal moves that a king can make in chess. This is the most commonly used neighbourhood algorithm in GIS and is represented in Figure 1.12B. **Modified Moore -** Connecting the cell centres using this method combined both the Knight's and Kings' moves. Connecting cells in 16 directions may increase the accuracy of calculations [van Etten, 2017].

Figure 1.12 Representation of neighbourhoods in accessibility analyses. The red cell is the cell of interest, for which neighbourhood is to be defined. A) the von Neumann neighbourhood. The four green cells are considered the neighbours in this algorithm given their orthogonal connection to the cell of interest. B) Representation of the Moore neighbourhood. The red cell is the cell of interest, for which neighbourhood is to be defined. The eight green cells are considered neighbours. C) Representation of the 16-neighbourhood algorithm that combines Moore's neighbourhood with additional movement as the Knight moves.




Once the neighbourhood is selected, the next step is to choose the least-cost path, with cost again referring to the 'easiest root' explained in Section 1.6.1 above. This can be done considering the resistance of the neighbouring cells or the weighted cost which defines how difficult it is to cross a cell.

### 1.7.3 Methods of adjusting for slope

The speed at which individuals can walk is determined by the slope. Ideally, the speed of travel reduces with increasing slope but also increases slightly with reducing slope. Three models have been proposed to characterise how walking speeds change with slope. These are the Tobler's hiking function [Tobler, 1993], the Naismith-Langmuir rule [Langmuir, 1984] and the approach developed by Rees [Rees, 2004]. The Tobler's hiking function was developed based on empiric data on walking speeds summarised as;

$$W = 6e^{-3.5\left|\frac{dh}{dx}+0.05\right|} \quad \text{Equation 1.1}$$

Where W is the walking speed (Km/hr), dh is the elevation difference, dx is the distance for which the elevation distance is being measured, *dh* is the slope vertical distance while *dx* is the horizontal distance. Assuming the normal walking speed of 5Km/hr, then the maximum speed of 6 Km/hr is achieved at a slope of -2.86°. On a flat terrain, this formula works out to 5 Km/hr.

The basic rule of Naismith-Langmuir rule is that a speed of 5 km/hr is maintained by a walker on flat terrain but one hour is added to every 600 m of ascent. The rule is thought to give reasonable minimum travel times but is also considered optimistic for regular walking [Langmuir, 1984]. With this rule, the maximum travel speed is achieved at 7 km/hr at a slope of -12°.

A more advanced approach was proposed by [Rees, 2004], in an attempt to predict the least cost paths in mountainous regions. He suggested that the differences in speed across different terrains is characterised by a quadratic function.

$$\frac{1}{v} = a + bm + cm^2 \text{ Equation 1.2}$$

Where v is the speed and m the slope. The coefficients a, b and c were also found to be 0.75 s/m, b = 0.09 s/m and c=14.6 s/m respectively. The coefficient a defines the travel speed of 4.8 km/h on a flat ground while c defines the rate of decay of speed as slope increases. This method favors the indirect path, walking zig zag instead of walking straight from a critical slope value.

### 1.7.4 Summary on spatial accessibility models

As is described in each method, there is no single model that is the 'gold standard' for measuring spatial accessibility and therefore analysis of the advantages and disadvantages of each is key before choosing the most plausible. Because of the time to adverse outcomes for different aetiologies and diseases vary, what is considered as optimal geographic access varies. The geographic access threshold may be lower for primary care than for emergency services for example and assessment of geographic access requires a focus on specific conditions.

## 1.8 Review of methods used to define geographic access to CEmONC services

The objectives of this review were to: 1) provide an overview of the methods used to define spatial access to emergency care; 2) establish the critical time/distance thresholds used to define physical accessibility; and 3) what is frequently used to parameterise accessibility models. A systematic search of literature was conducted to synthesize and summarise evidence using articles indexed in PubMed and Medline. The search was conducted September 2017. Studies were restricted to those conducted in SSA. Studies were chosen if they primarily analysed spatial access to CEmONC services including caesarean section, the most common surgical procedure in Africa. Those whose primary aim were to analyse spatial access to primary level services were excluded even if the analysis included hospitals. An exception to this was however made if studies presented a separate assessment of geographic access to hospital services from the primary level facilities. There was no restriction on the study design to be included in the review. Subsequently, their references were scanned for other papers that may have been missed. The article extraction strategy summarized Table 1.12 and Figure 1.13. A summary of the methods used in each study is presented in Table 1.13. These were restricted to those published in SSA and after the year 2000. This is the year when accelerated investments in health were made, after the adoption of the millennium development goals.

Table 1.12 Review of the methods used to define spatial access to emergency care

a. *Countries*

| | | |
|---|---|---|
| SSA OR "sub-Saharan Africa" OR Africa | 33,453 | OR |
| Angola or Benin or Botswana or Burkina Faso or Burundi or Cameroon or Cape Verde or Central African Republic or CAR or Chad or Comoros or Congo or Cote d'Ivoire or cote dIvoire or Ivory Coast or DRC or Djibouti or Equatorial Guinea or Eritrea or Ethiopia or Gabon or Gambia or Ghana or Guinea or Guinea-Bissau or Kenya or Lesotho or Liberia or Madagascar or Malawi or Mali or Mauritania or Mauritius or Mozambique or Namibia or Niger or Nigeria or reunion or Rwanda or "Sao Tome and Principe" or Senegal or Seychelles or Sierra Leone or Somalia or South Africa or Sudan or Swaziland or Tanzania or Togo or Uganda or Western Sahara or Zambia or Zimbabwe | 169,399 | 187,394 |

b. *Geographic accessibility*

| | | |
|---|---|---|
| ((spatial OR geographic OR geospatial OR geospatial evaluation OR distance OR gis OR "geographic information systems" OR travel* OR timely OR distance* OR "catchment area (health)") | 92,234 | OR<br>296,958 |
| ((km? OR m? OR kilometre? OR meter? OR mile?) adj2 (at least OR more OR less OR within OR from OR to OR away OR walk OR drive OR ride OR bike OR cycle OR commut*))) | 12,990 | |

c. *Emergency obstetrics and neonatal care*

| | | | | |
|---|---|---|---|---|
| (facilit* or hospital* or institut* or non-institut* or noninstitut* or clinic? or center? or centre? or department? or unit? or ward? or place) | 15631319 | | | OR<br>237791 |
| (attend* or birth attend* or health or assistant* or care or manpower or delivery or staff or midwif* or professio*) | 5960556 | | | |
| Birthing centers/ or Delivery rooms/ or Delivery, obstetric/ | 93477 | | | |
| Birth* or Childbirth? or Deliver* or Labo?r or Parturition or Pregnan* or Obstetrics/ or Parturition/ or Pregnancy/ | 1879759 | | AND<br>176186 | |
| Physicians/ or doctor* or physician* or Midwifery/ or midwi* or nurses/ or nurse* or obstetrical nursing/ or Professional practice/ or Health personnel/ or ((clinical or health of medical) adj1 (officer* or auxiliary*)) | 1531191 | OR | | |
| "Delivery of Health Care"/ or "Obstetrics and Gynecology Department, Hospital"/ or Health Behavior/ or Health facilities/ or Health Facility Closure/ or Health Personnel/ or Health Services/ or Healthcare Disparities/ or Maternal Health Services/ or Maternal-Child Health Centers/ or Universal Coverage/ | 3341373 | | | |
| ((health* or medical) adj3 (utiliz* or utilis* or use* or uptake* or access*)) | 141332 | | | |

a + b + c (limited to year > 2000) = 632

Figure 1.13 Article extraction flow diagram exercise showing the inclusion and exclusion criteria

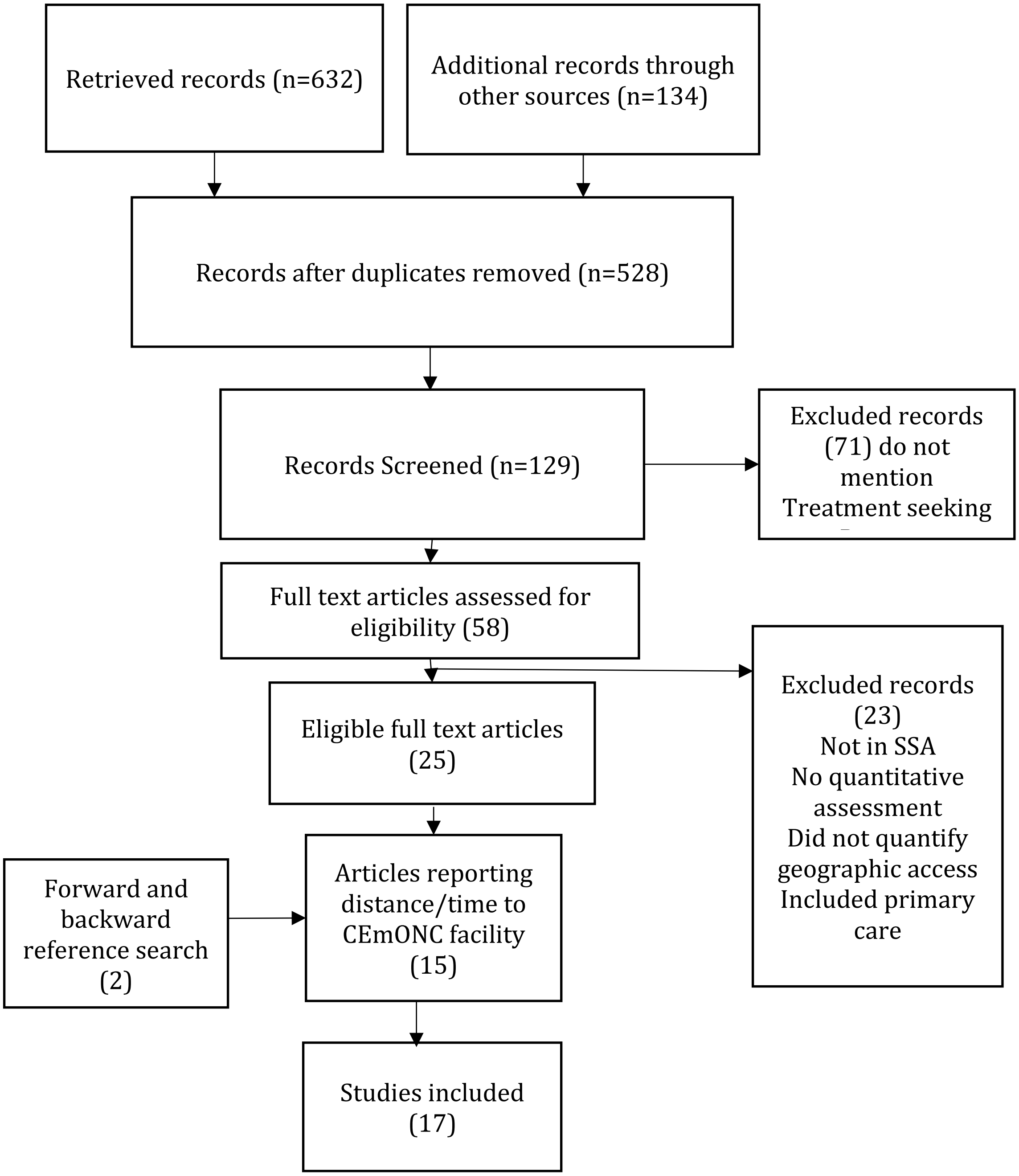


Table 1.13 Summary of methods used to measure spatial access to CEmONC services in LMICs ordered showing the access measure, catchment areas used, method of analysis and parameters of road speeds. Articles arranged based on method of measuring access. OSM stands for OpenStreetMaps. Caesarean section is a major surgical

| **Author** | **Access measure** | **Catchment area** | **Method** | **Roads & Travel speeds (Km/h)** | **Service** | **Country** |
|---|---|---|---|---|---|---|
| Tansley et al., 2017 | Minimum travel time | NA | Cost distance | OSM roads; 100, 50, 30, 5 for primary, sec, tertiary roads, and background cells respectively | Surgery | Ghana |
| Esquivel et al., 2016 | Minimum travel time | 2 hours | Cost distance | OSM roads obtained from OSM; speeds also from OSM | Surgery | Zambia |
| Stewart et al., 2016 | Minimum travel time | 1 & 2 hours | Cost distance | OSM roads; speeds of 100, 50, 30, 5 for primary, sec, tertiary roads, and background cells respectively | Surgery | Ghana |
| Knowlton et al., 2017 | Minimum travel time | 2 hours | Cost distance | OSM roads obtained from OSM; speeds also from OSM | Surgery | Ethiopia, Liberia, Rwanda |
| Pirkle et al., 2011 | Minimum travel time | NA | Time taken | NA | Obstetrics | Mali |
| Alkire et al., 2015 | Minimum travel time | NA | % Pop using ambulances | NA | Surgery | Global |
| Raykar et al., 2015 | Minimum travel time | 2 hours | Cost distance | Roads from google map maker | Surgery | Somaliland, Botswana, Ethiopia, Rwanda, Namibia, Zimbabwe and Sierra Leone |
| Chen et al., 2017 | Minimum travel time | 2 hours | Cost distance | OpenStreetMap; Speeds vary based on scenarios used | Obstetrics | Tanzania |

Table 1.13 Continued…

| Author | Access measure | Catchment area | Method | Roads & Travel speeds (Km/h) | Service | Country |
|---|---|---|---|---|---|---|
| Smith et al., 2017 | Travel distance | Voronoi diagram | Straight line distance | NA | Surgery | Uganda |
| Lohela et al., 2012 | Travel distance | NA | Straight line distance | NA | Obstetrics/Newborn care | Malawi, Zambia |
| Leslie et al., 2016 | Travel distance | NA | Straight line distance | NA | Obstetrics/Newborn care | Malawi |
| McKinnon et al., 2014 | Travel distance | 80 Km | Straight line distance | NA | Obstetrics | Ethiopia |
| Faierman et al., 2015 | Travel distance | NA | Straight line distance | NA | Surgery | Mozambique |
| Kashima et al., 2012 | Travel distance | 30 Km | Straight line distance | NA | Newborn care | Madagascar |
| Hanson et al., 2015 | Travel distance | NA | Straight line distance | NA | Emergency obstetrics | Tanzania |
| Gabrysch et al., 2012b | Travel distance | 15 Km | Straight line distance | 5 | Obstetrics | Zambia |
| Høj et al., 2002 | Travel distance | 5, 25 Km | Straight line distance | NA | Obstetrics | Guinea Bissau |

**Footnote:** NA; Not applicable

Description of the studies included in this review is shown in Table 1.12. A total of 17 studies were reviewed. Most of the studies (n=8) were specific to surgery, of which caesarean section is one of the surgical procedures, while others focused on obstetrics (n=6), neonatal care (n=1), or a combination of both obstetrics and neonatal care (n=3). However, it is worth noting that overlaps probably existed especially in the case of caesarean section and surgery.

#### 1.8.1.1 Methods and data sources

The reviewed studies used a variety of methods in defining access, and these included cost distances, straight line distance and reported travel time. Due to its simplicity (Section 1.7.1), straight line/Euclidean distances were used in nine studies while six used the cost distance method Table 1.13. In one study, reported travel time [Pirkle et al., 2011] was used, and one study measured timeliness as the proportion of population being transported by ambulances [Alkire et al., 2015]. Of the seven studies which used road network data, five adopted OpenStreetMaps, justifiably so given it is the most common freely available source of spatial data. However, OpenStreetMap, often relies on voluntary geographic information (VGI) or crowd sourced data which is prone to errors due to lack of proper checks [Dorn et al., 2015]. Only used google mapmaker resource [Tansley et al., 2015].

#### 1.8.1.2 Catchment areas

In the nine studies which used distance (in Km), the threshold distance varied from 5 to 80 Km. There are few recommendations for geographic access that are pegged on straight line distances and this is reflected in the wide variation in choice of threshold distance. Despite simplicity in its implementation, justifying the use of straight-line distances is difficult. Conversely, six of the nine studies which used travel time to measure access used the two-hour threshold, and this consistency highlights the utility of travel time compared to straight line distances.

#### 1.8.1.3 Travel time parameters and sensitivity analysis

Defining transport parameters (speed and roads used) is important in the cost distance analysis. There was a significant variation in travel speeds assigned to road networks. Tertiary, secondary and primary roads speeds were typically assigned 100, 50 and 30 Km/hr respectively [Stewart et al., 2016; Tansley et al., 2017]. However, only one study extracted speeds from those reported in OpenStreetMap roads although preliminary checks showed that very few roads have the speeds indicated [Knowlton et al., 2017a]. Sensitivity analysis also commonly involves adjusting original travel speeds by ±20% which can be used to provide uncertainty. The accuracy of an accessibility model depends on the parameters used. These include modes of transport and speeds across each land use. To account for changing speeds, four studies reviewed performed sensitivity analysis, by varying travel speeds by ±20% showing uniform differences between the accessibility ranges[Tansley et al., 2015, 2017; Esquivel et al., 2016; Stewart et al., 2016].

#### 1.8.1.4 Summary of gaps in previous studies

All the studies in the review (Table 1.12) assume motorised transport is readily available at all roads. Transportation, however, is a complex undertaking that often varies depending on a multitude of factors. In rural areas for example, availability of motorised transport may be a challenge and cannot be equated to road proximity. The choice of transport means, when it is available and at what point patients seek and use transport would affect accessibility model outputs. To highlight the significance of this problem [Chen et al., 2017] show that assuming motorised travel is universal, increases population within 2 hours by 20% compared to using a model that assumes walking only. Thus, accessibility can be over- or underestimated if not well parameterised. Studies reviewed, therefore, used poorly calibrated accessibility models, which do not account for the realities of transportation. All the studies that modelled cost distance analysis were not specific on neighbourhood structure used but these were assumed to use the

Moore neighbourhood as is the default used in AccessMod and ArcGIS software. These models are fixed and may present challenges in case modification is needed. The availability of R analytical tool offers an opportunity for improving the modelling of accessibility.

To improve the accessibility model used in this work, a review of literature was conducted to summarise information on how patients with emergency conditions access hospitals and modes of transport used (Section 1.9). This will inform the assignment of motorised transport to specific roads, a critical step which should avoid over estimation of access observed in the previous studies.

## 1.9 Transportation and health treatment seeking pathways in SSA

Transportation and healthcare are inextricably linked, and the way people travel, where they go and at what time influence access to healthcare [Jacobs et al., 2012]. The African Federation of Emergency Medicine (AFEM), recognises transport as a key barrier towards improving health outcomes, because it can alter the effect of distance as an indicator of physical access [Abujaber et al., 2016]. The aim of this review was to examine, people's modes of transport, pathways to hospital care, barriers encountered and the specific facilitators to provide better parameterisation of spatial accessibility models for empirical work in the thesis.

Pubmed and Medline databases were systematically searched for studies on emergency obstetric transport in LMICs. The search was done between October 2017 with the search strategy presented in Table 1.14 and article extraction in Figure 1.14.

Table 1.14 Search strategy for extraction of articles for reviewing transportation and health treatment seeking pathways in SSA

a. *Sub-Saharan Africa*

| | | |
|---|---|---|
| SSA OR "sub-Saharan Africa" OR Africa | 33,453 | OR |
| Angola or Benin or Botswana or Burkina Faso or Burundi or Cameroon or Cape Verde or Central African Republic or CAR or Chad or Comoros or Congo or Cote d'Ivoire or cote dIvoire or Ivory Coast or DRC or Djibouti or Equatorial Guinea or Eritrea or Ethiopia or Gabon or Gambia or Ghana or Guinea or Guinea-Bissau or Kenya or Lesotho or Liberia or Madagascar or Malawi or Mali or Mauritania or Mauritius or Mozambique or Namibia or Niger or Nigeria or reunion or Rwanda or "Sao Tome and Principe" or Senegal or Seychelles or Sierra Leone or Somalia or South Africa or Sudan or Swaziland or Tanzania or Togo or Uganda or Western Sahara or Zambia or Zimbabwe | 169,403 | 187,394 |

b. *Transport modes*

| | | |
|---|---|---|
| Transport* OR access* OR Movement OR transfer OR ambulance, motorbike ambulance, bicycle ambulance, emergency referral, emergency access, emergency transport, and ambulance emergency | 1,876,185 | AND<br>306,029 |
| Hospitals OR health* OR hospital* OR comprehensive care OR skilled care | 7,428,116 | |

c. *Emergency care*

| | | |
|---|---|---|
| Trauma* OR Inju* OR Surg* OR Very ill OR severely ill OR acute OR emergency OR life threatening OR Critical* OR Severe* | 2,590,866 | 2,590,866 |

a + b + c (limited to year > 2000) = 5392

Figure 1.14 Selection criteria for desired articles

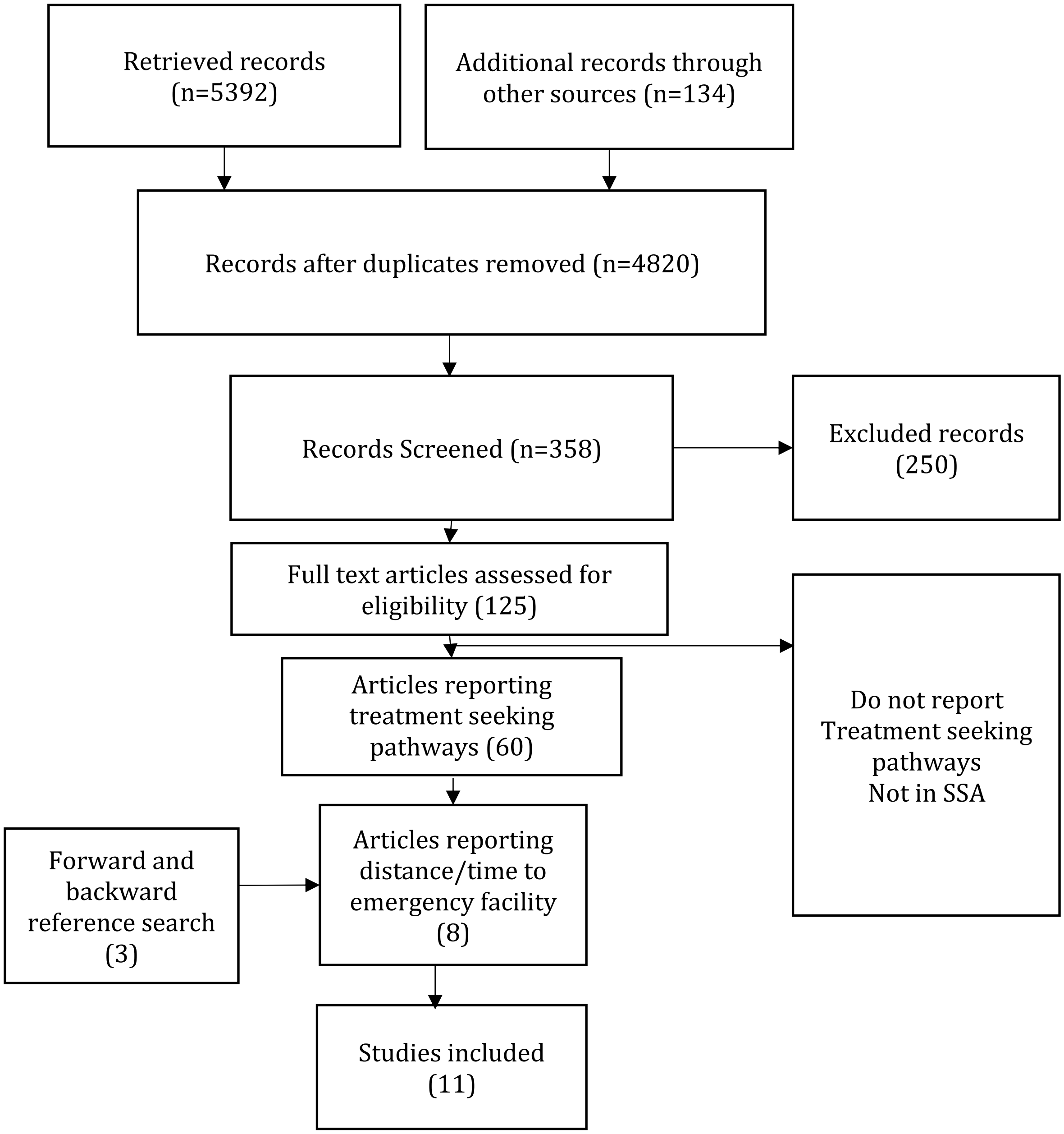


Table 1.15 Characteristics of studies included in the review showing the sampled participants, modes of transport the setting and summary findings of each study.

| **Author** | **Sample size** | **Method of data collection** | **% Motorized** | **Main Mode of Transport** | **Condition** | **Country** | **Level** | **Findings** |
|---|---|---|---|---|---|---|---|---|
| [Elmusharaf et al., 2017] | 28 | Qualitative | NA | Private Vehicle | Obstetrics | South Sudan | One Region | With transport a challenge at marginalized communities, many prefer using any means to get to towns or higher-level roads where motorized transport is available. |
| [Sacks et al., 2016] | 790 | Qualitative & Quantitative | 74 | Motorcycle taxi | Obstetrics | Uganda | 4 districts | In Uganda, most women prefer using private motorized taxis to get to hospitals |
| [Sacks et al., 2016] | 843 | Qualitative & Quantitative | 93 | Taxi | Obstetrics | Zambia | 5 districts | Pregnant women prefer vehicular transport as there was fear that bicycle transport promoted by the FMGL program was slow |
| [Broccoli et al., 2015a] | 528 | Qualitative | NA | Private Vehicle | Obstetrics | Kenya | National | Communities understand the time-critical nature of emergencies. They rely on one another for assistance in the face of substantial barriers to care—a lack of: system structure, resources, transportation, trained healthcare providers and initial care at the scene. |
| [Niyitegeka et al., 2017] | 441 | Quantitative | 100 | Ambulance | Neonatal | Rwanda | 3 hospitals | Longer travel poor roads and transport availability increased delays in seeking care thus increasing mortality rates |

Table 1.15 Continued…

| Author | Sample size | Method of data collection | % Motorized | Main Mode of Transport | Condition | Country | Level | Findings |
|---|---|---|---|---|---|---|---|---|
| [Calvello et al., 2016] | 183 | Quantitative and Qualitative | 100 | Motorized | Trauma, Obstetrics, Surgery | Kenya | National | About 70% of the community members had experienced an emergency condition at one time and majority seem to understand their time critical nature. Majority of patients seek care at the nearest government facilities. |
| [Stein et al., 2016] | 1004 | Quantitative and Qualitative | 83 | Taxi | Obstetrics | Ghana | One urban region | Despite half of the population knowing about availability of ambulatory services, majority still preferred using taxis as the mode of transport for patients in need of emergency care. This was attributed to longer response times in the case of ambulance services compared to taxi transport which is seen to be readily available. |
| [Essendi et al., 2011] | NA | Qualitative | NA | NA | Obstetrics | Kenya | Urban Slum area | Study finds and reports a number of challenges faced by women in need of emergency obstetric care. A number cannot identify danger signs, which leads to poor health decision making, unaffordability, poor road network in slums meaning that parturient women have to walk to the nearest main road. |
| [Butrick et al., 2014] | 616 | Quantitative | 98.8 | Ambulance | Obstetrics | Zambia | Three districts | 93% of women at 24 weeks of pregnancy or more were transported by ambulance compared to 67% of women at less than 24 weeks. |

Table 1.15 Continued…

| Author | Sample size | Method of data collection | % Motorized | Main Mode of Transport | Condition | Country | Level | Findings |
|---|---|---|---|---|---|---|---|---|
| [Tayler-Smith et al., 2013] | 1478 | Quantitative | 100 | Ambulance | Obstetrics | Burundi | One rural district | The time between calling for an ambulance and getting to the referral facility ranged from 52 to 130 minutes, showing that motorized transport is always preferred but ambulances not available |
| [Atuoye et al., 2015] | 95 | Qualitative | | NA | Obstetrics | Ghana | One region | Lack of transport was the major barrier to timely access to obstetric care in addition to geographical barriers such as distance and transportation network availability |

**Footnote:** NA; Not applicable

### 1.9.1 Summary of Literature

Eleven studies were assessed, 10 of which were in obstetrics and only one was for newborns. But even this one study used access to caesarean section hospitals. Four of the studies exclusively used either a qualitative or a quantitative method, while the remaining four used a mixed method, where both qualitative and quantitative analyses were conducted.

### 1.9.2 Motorised Transport

Eleven studies quantified motorised transport as the most commonly used means of getting to hospitals. The use of ambulances was reportedly low, most patients preferring to use other means of motorised transport such as private vehicles, taxis and motorcycles [Essendi et al., 2011; Nielsen et al., 2012; Tayler-Smith et al., 2013; Atuoye et al., 2015; Mould-Millman et al., 2015; Raj et al., 2015; Broccoli et al., 2016; Calvello et al., 2016; Niyitegeka et al., 2017]. These are often thought of as cheaper, faster and readily available [Mould-Millman et al., 2015; Calvello et al., 2016; Sacks et al., 2016]. Even in urban populations of Ghana where ambulance availability and knowledge was high, private and commercial means of transport were still preferred [Mould-Millman et al., 2015]. In some settings, public transport modes such as taxis, motorcycles and buses were the only available means of motorised transport, although at more localised levels, patients may have to get to main roads or major market centres.

### 1.9.3 The role of non-motorised means of transport

There are a number of community specific means of transport which are used in remote areas to transport patients who are immobilised due to acuity of their conditions [Holmes & Kennedy, 2010]. These include hammocks, stretchers, baskets, animal carts, boats and bicycles [Holmes & Kennedy, 2010], which are mainly used in the absence of any motorised forms of transport [Atuoye et al., 2015; Elmusharaf et al., 2017]. In rural areas where terrain is rough, extreme weather conditions such as rain and heat can make it difficult to use non-motorised means of transport for long distances [Munjanja et al., 2012]. In South Sudan for example, patient experiences when seeking comprehensive emergency obstetric care for marginalised communities include the use of donkey driven carts, bicycles, bicycle ambulances and carriage on stretchers [Elmusharaf et al., 2017]. These methods are mostly used in the absence of motorised transport modes and are often used to get to locations such as major roads or market centres, from where motorised transport is likely to be obtained. In Kenya, similar experiences have been observed, and walking was used by 18% of the patients arriving at an emergency department of a national referral hospital, while smaller proportions (9%) were carried [House et al., 2014; Broccoli et al., 2015b; Myers et al., 2017].

### 1.9.4 Transportation challenges

Several challenges exist towards obtaining transport to health services which include cost, availability and other social and cultural factors. Others are related to infrastructure, such as the roads getting poor during the rainy seasons, a situation which creates poorer accessibility [Makanga et al., 2017]. These challenges vary between communities and countries and in some instances are affected by national policies or interventions [Sacks et al., 2016]. In an urban slum of Kenya, women in need of emergency care reported cost and unavailability of ambulances as an impediment to accessing health services, majority being forced to walk to major roads before obtaining motorised transport [Essendi et al., 2011]. Multiple or delayed referrals are also significant barriers. In Burundi for example, referral times of more than 3 hours for women needing emergency obstetric care were associated with increased mortality [Tayler-Smith et al., 2013]. A qualitative study in South Sudan highlighted the poor referral practises in the country, where patients may be referred multiple times to facilities without the necessary care [Elmusharaf et al., 2017].

### 1.9.5 How accessibility models can be improved

The two reviews reveal some important insights into how patients access hospital care. First, majority of the patients are likely to use motorised transport to get to hospitals, and in a community assessment in Zambia and Kenya, this is attributed to knowledge of the time-sensitive nature of many emergency conditions. Secondly, motorised transport is often not available in rural areas and patients use other non-motorised means to get to major towns or major roads where motorised transport can be available. Therefore, assuming transport is readily available at every road, would overestimate accessibility. Ambulances are rarely used, given their unavailability, poor records of physical addresses and perception that they are always unreliable and accessibility models would have to include the journeys from health facility to home then to health facility again, essentially underestimating access. Besides, ambulances are typically often used to pick patients from lower-level facilities due to their scarcity hence they are not normally reported as a source [Wilson et al., 2013]. Other factors such as waiting times for public transport may also affect accessibility models, but this may vary at individual and hospital levels, making their integration in a continental or national model difficult.

Thus, as part of this study, accessibility models will be built that account for some of the observed gaps in the previous literature. First, motorised transport will be assumed to be available only on the major roads; classes A, B and C, while all other areas will be assigned non-motorised means of transport (Section 2.2.4). Secondly, the role of ambulance use will not be accounted for as patients, from the literature in SSA, are more likely to use other means of motorised transport. This model should provide a more realistic depiction of geographic access in SSA.

This previous section focused on access to healthcare, the methods used to define geographic accessibility to emergency care and some of the shortcomings. Given that poor geographic access is a barrier towards obtaining services, the next section provides a review of the relationship between geographic access and mortality. The expectation is that poorer access is related to increasing mortality.

## 1.10 The relationship between geographic access and maternal and neonatal mortality

Poor access poses a significant barrier to obtaining health services during a pregnancy period [Barber et al., 2017]. Consequently, poor geographic access to maternal services puts the mother and child at greater risk of adverse outcomes such as mortality. This section reviews previous studies that have investigated such relationships, with an additional focus on the covariates commonly used to assess the relationships.

### 1.10.1 Reviewing the impact of poor geographic access on mortality

As shown in Section 1.6 a significant proportion of maternal and neonatal deaths can be reduced by ensuring access to emergency obstetric and neonatal care. Timely access to emergency facilities is therefore critical for managing these life-threatening conditions. Understanding the role of poor access on outcomes can help identify areas which require greater attention. However, there has been no review of the influence of access to hospitals/emergency care on mortality in SSA. The objective of this review was to assess outcome of articles which have examined the relationship between access to emergency care and mortality, factors that may confound this relationship and the methods used to evaluate the relationship between outcome and geographic access. Articles that met inclusion criteria were those which examined the relationship between access to hospital/emergency care and mortality and included a host of covariates in the analysis. The search was done using Medline and PubMed, using the search strategy shown in Table 1.15 and Figure 1.15 strategy was completed on December 2018.

Table 1.16 Search strategy for extraction of articles used in reviewing the impact of poor geographic access on mortality

a. *Sub-Saharan Africa*

| | | |
|---|---|---|
| SSA OR "sub-Saharan Africa" OR Africa | 33,453 | OR |
| Angola or Benin or Botswana or Burkina Faso or Burundi or Cameroon or Cape Verde or Central African Republic or CAR or Chad or Comoros or Congo or Cote d'Ivoire or cote dIvoire or Ivory Coast or DRC or Djibouti or Equatorial Guinea or Eritrea or Ethiopia or Gabon or Gambia or Ghana or Guinea or Guinea-Bissau or Kenya or Lesotho or Liberia or Madagascar or Malawi or Mali or Mauritania or Mauritius or Mozambique or Namibia or Niger or Nigeria or reunion or Rwanda or "Sao Tome and Principe" or Senegal or Seychelles or Sierra Leone or Somalia or South Africa or Sudan or Swaziland or Tanzania or Togo or Uganda or Western Sahara or Zambia or Zimbabwe | 169,399 | 187,394 |

b. *Geographic access*

| | | |
|---|---|---|
| ((spatial OR geographic OR geospatial OR geospatial evaluation OR distance OR gis OR "geographic information systems" OR travel* OR timely OR distance* OR "catchment area (health)") | 92,526 | OR<br>296,958 |
| ((km? OR m? OR kilometre? OR meter? OR mile?) adj2 (at least OR more OR less OR within OR from OR to OR away OR walk OR drive OR ride OR bike OR cycle OR commut*))) | 13,051 | |

c. *Mortality indicators*

| | | |
|---|---|---|
| death* OR dead OR died OR mortalit* OR surviv* | 372,342 | AND |
| Mothers OR maternal OR newborn OR babies OR infant* OR perinat* OR neonat* OR postneonat* pre-school OR child* OR under-five OR postneonatal OR infant OR Under 5 | 726,527 | 726,532 |

a + b + c (limited to year > 2000) = 10,559

Figure 1.15 Article extraction flow diagram

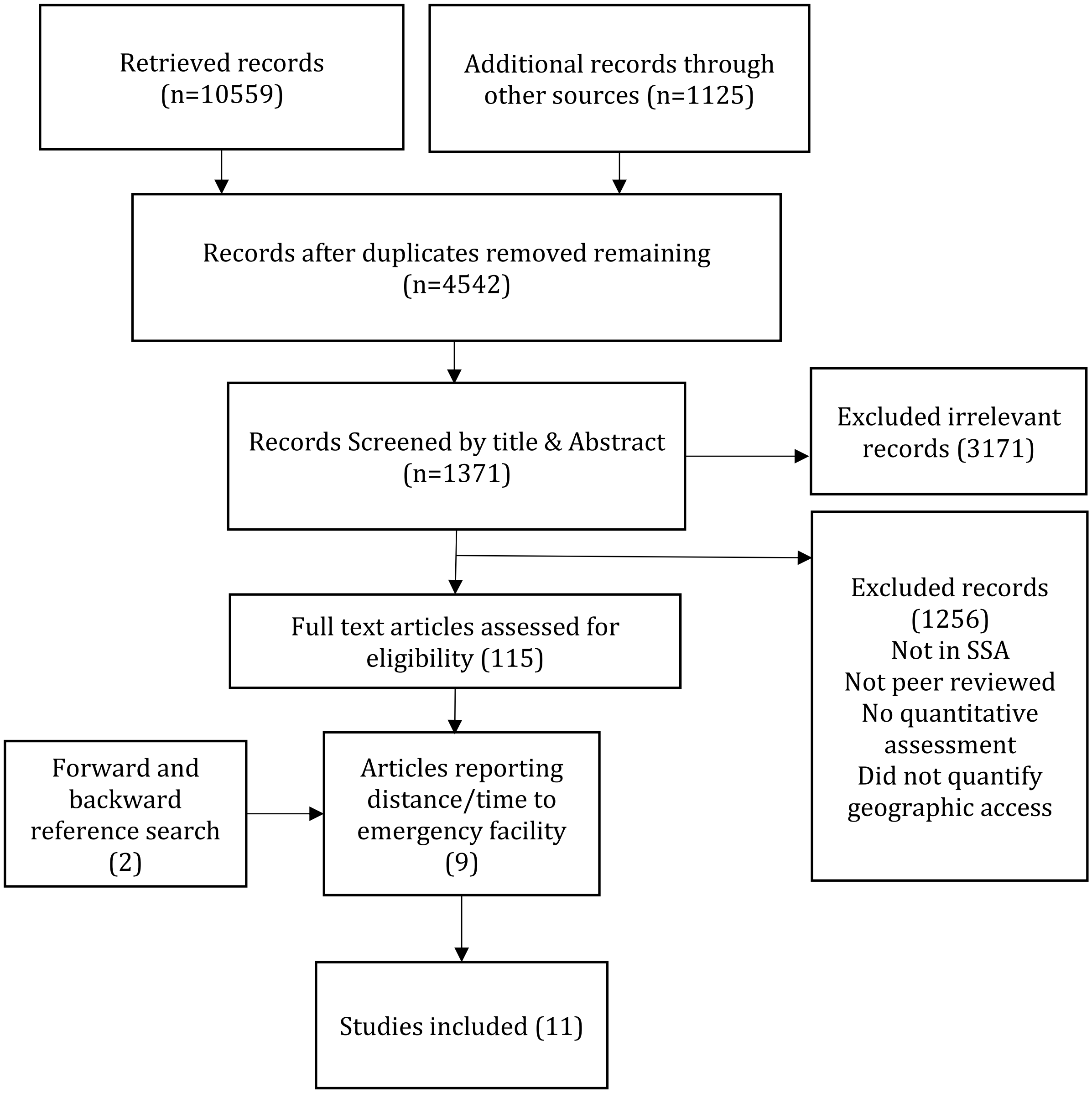


Table 1.17 The relationship between access and mortality. ↑ shows mortality increases with poor access.

| Author | Critical distance/Time | Outcome | Country | Method of statistical analysis | Covariates/Confounders included in multivariable analyses | Relationship | Arrow |
|---|---|---|---|---|---|---|---|
| Kadobera et al., 2012 | 5 Km | Infant mortality | Tanzania | Cox Proportional hazard models | Age of child, gender, maternal age, maternal death, death of preceding child/sibling and district of residence | Survival probability of U5 children was higher for children living <5 Km compared to those who lived > 5 Km to a health facility. | ↑ |
| Hanson et al., 2015 | 30 Km | Maternal mortality | Tanzania | Multilevel logistic regression | Wealth, ethnicity, district and education of household head | After 30 Km distance to hospitals, there was a fourfold increase in maternal mortality compared to <1 km | ↑ |
| Hoj et al., 2002 | 25 Km | Maternal mortality | Burkina Faso | Multivariable logistic regression | Age, diagnosis, and date of arrival. | Living more than 25 Km from a hospital was associated with an increased odd of death by 7 | ↑ |
| Pirkle et al., 2011b | 4 hours | Maternal mortality | Mali | Multivariable logistic regression | Age, diagnosis and date | Case fatality rate increased with increasing travel time; 1.72% for <2h, 2.72 for 2-3h and 5.49 for >4h. A travel time of more than 4 h was significantly associated with a maternal death. | ↑ |
| Kashima et al., 2012 | 5 Km | Neonatal & Infant Mortality | Madagascar | Multilevel mixed effects logistic regression | Malaria endemicity, maternal anemia, vaccination coverage, household wealth, maternal education. | Neonatal and infant mortality increased among those who lived > 5 Km to the nearest facility. | ↑ |
| Lohela et al., 2012 | 10 km | Neonatal mortality | Malawi, Zambia | Multivariable regression model | Birth order, twin, weight, sex, parity, < 7 years of age, wantedness of pregnancy, age, literacy, husband's occupation, education, occupation, ethnicity, religion, marital status, husband's education, relationship autonomy, media use, fertility attitudes, women's autonomy, wealth index. | There was no association between distance and neonatal mortality. The level of care provided also showed no association with neonatal mortality. In Zambia, increasing distance to health facilities per 10 Km was associated with lower mortality (OR 0.55). In addition, there was no association between early neonatal mortality and the level of care. | None |

Table 1.17 Continued…

| Author | Critical distance/Time | Outcome | Country | Method of statistical analysis | Covariates/Confounders included in multivariable analyses | Relationship | Arrow |
|---|---|---|---|---|---|---|---|
| Leslie et al., 2016 | | Neonatal mortality | Malawi | Multivariable regression model with an IV component | Wealth index, education (above secondary), maternal age, marital status, parity, adolescence, ANC, gender, multiple birth and LBW. | Access to improved facility quality was associated with reduced mortality | ↑ |
| McKinnon et al., 2014 | 80 Km | Neonatal mortality | Ethiopia | Multivariable logistic regression. | Maternal age, sex, birth order, birth interval, multiple birth, maternal education, wealth, women autonomy | The odds of neonatal mortality was 14.46 more in children from households more than 80 Km of a CEmONC compared to those less than 10 Km to a CEmONC. | ↑ |
| Karra et al., 2017 | 10 Km | Neonatal Mortality | LMICs | Multivariable logistic regression | Wealth, maternal education, maternal age, birth order, marital status, residence, child age, child gender, average cluster education and av cluster wealth to control for spatial differences, year and time of survey | Relatively small distances to health facilities are associated with changes in neonatal mortality. | ↑ |
| Tayler-Smith et al., 2013a | 3 hours | Neonatal mortality | Ethiopia | Univariate logistic regression | None | Neonatal deaths in mothers who arrive to a hospital increased after 3 hours of being referred was two times higher than those who arrived less than this time. | ↑ |
| Niyitegeka et al., 2017 | 1.5 hours | Neonatal mortality | Rwanda | Chi square tests | Primary data collected on woman's age, gestational age, number of fetuses, systolic blood pressure | Neonatal outcomes in mothers traveling more than 90 minutes was five times higher than those travelling less than ninety minutes | ↑ |

#### 1.10.1.1 Access and outcome

Of the 11 studies in this review (Table 1.17) three used maternal mortality as the outcome while eight used neonatal deaths as an outcome [Hoj et al., 2002; Pirkle et al., 2011; Hanson et al., 2015]. The geographic access metric used to assess elevated mortality estimates varied depending on whether distance was used or travel time. Distance varied from 5 to 80 km while travel time varied from one and a half hours to 4 hours. Data on neonatal mortality is often available from household survey data and this allows for controlling for a range of individual, household and community confounders [Lohela et al., 2012; McKinnon et al., 2014; Leslie et al., 2016; Karra et al., 2017]. With the exception of one study [Lohela et al., 2012], the other 10 show that poor accessibility is related to poor outcomes i.e. living further away from a hospital increases the risk of mortality. This influence was however different between studies and there was no consensus on the exact travel time/distance threshold where mortality significantly increases. This potentially is due to differences in measuring geographic accessibility.

For maternal mortality, two studies found critical distances beyond which mortality is likely to increase significantly to be 30 Km [Hanson et al., 2015] and 25 Km [Hoj et al., 2002]. Only one study used travel time [Pirkle et al., 2011], and found that after 4 hours, maternal deaths were increased fourfold compared to those living within 1 hour. This time threshold is double the 2-hour threshold proposed by the WHO and this could be attributed to the fact that it was a hospital-based study where women are likely to come from very far, with some referred from lower-level facilities.

#### 1.10.1.2 Covariates used

Mortality can be affected or aggravated by factors other than accessibility. Therefore, the studies included in this review incorporated other variables into the statistical models assessing the role of access on mortality. These can be grouped as either intrinsic or extrinsic factors. None included information on the quality of care at the hospitals. Multivariable regression models are commonly used to define the relationships.

These variables affect mortality differently depending on the area of analysis. For example, one study shows age to not affect child mortality [Manongi et al., 2014], the effect was much more significant in another study done in the same country [Kadobera et al., 2012]. None of the studies used the full range of covariates presented in Table 1.18, despite some being readily available. For example, there are covariates which were not used, and it is also important to control for factors affecting distance as demonstrated in the conceptual frameworks in Section 1.6. These can be specified using spatial regression models that account for residences. A summary of the covariates is shown in Table 1.18.

Table 1.18 Covariates that studies in the review used in assessing the relationship between access and mortality in the studies reviewed.

| **Level** | **Neonatal Mortality** | **Maternal mortality** |
|---|---|---|
| Individual | Maternal education | Ethnicity |
| | Ethnicity | Maternal Education |
| | Birth Order | Age |
| | Twin birth | Direct cause |
| | Pregnancy wantedness | Nutritional status of the mother |
| | Maternal age | |
| | Occupation | |
| | Religion | |
| | Media use | |
| | Woman's financial autonomy | |
| | Adolescent birth | |
| | ANC attendance | |
| | Low Birth Weight | |
| | Parity | |
| | Vaccination coverage | |
| | Migrant status | |
| Household | Wealth Index | Wealth Index |
| | Education of head | |
| | Husbands education | |
| Community | Malaria endemicity | |
| | Average cluster education | |
| | Average cluster wealth | |
| | Spatial effect | |
| Others | Time of the year | |
| | Access to lower-level facility | |

### 1.10.2 Gaps in literature

This review highlights specific information gaps. In describing the relationship between maternal mortality and spatial access, only five covariates have been accounted for, possibly due to the unavailability of data. In the thesis, the relationship between access to hospital care with maternal and neonatal mortality will be explored. Additional covariates that may confound this relationship as shown in Section 1.6.3 will be included in the assessment.

The previous three sections have focused on reviewing current literature on targets for healthcare, access to health care and the role geographic access to healthcare plays in variation observed in maternal and neonatal mortality. This thesis involves analyzing access and its relationship to mortality at the SSA level and a national level in Kenya. A contextual review of Kenya's health system, its current policies on maternal and neonatal health and summarizes some of the recommendations of geographic access to maternal and neonatal care will be provided in detail in Section 4.2.

## 1.11 Summary of literature and study justification

Access to CEmONC services is critical if SDG 3 targets of maternal and neonatal deaths are to be achieved in SSA. One limiting factor towards attaining equity in access to these services is geography, which can be affected by distance, transport and the terrain. Defining population access will, therefore, be key for identification of gaps and estimating where investments should be focused for attainment of health equity. To define geographic marginalisation, time thresholds for measuring access to CEmONC have been proposed, and while urgency for definitive obstetric and neonatal care varies with the type of complication, optimal access to these facilities is usually considered to be within 2 hours of travel time.

Despite the existence of this recommendation, there is still a dearth of studies effectively evaluating spatial access to these services (Section 1.8 review). The few that have done this are limited in the way geographic access is defined. For example, majority of the studies used straight-line distances as a measure of geographic access, despite the concept of access encompassing other barriers such as land use, proximity to roads and elevation. Other studies also use models that do not consider actual travel patterns (Section 1.9), neither do they account for the influence of weather patterns. Such exceptions provide poor estimates of those marginalised from hospital services. By extension, poor measurement of geographic access can affect studies that seek to evaluate the contribution of geographic access to poor outcomes (Section 1.10.1 review).

In this thesis, I describe the assembly of the first geocoded database of public hospitals in SSA countries and islands and this is used to model geographic access to public hospitals (Chapter 2). The national level access quotients are then compared to maternal and neonatal mortality using a linear regression model (Chapter 3). The accessibility analysis is improved by focusing the analysis on Kenya and evaluating and carefully selecting hospitals able to handle newborns with very low birth weight and offer caesarean section services using national health facility capacity assessment datasets (Chapter 4). Finally, accessibility metrics to these services in Kenya are then compared to maternal and neonatal mortality estimates in regression analyses using the counties (subnational health delivery units) as units of analysis (Chapter 5). The research questions guiding the analyses including the chapters where they are addressed are presented in Table 1.19.

Table 1.19 Research questions used in the study and how they are tackled in each Chapter. Table also shows the data used to answer questions in each Chapter.

| | **Questions** | **Data** |
|---|---|---|
| Chapter 2 | How many hospitals are in SSA and where are they?<br><br>What is the level of theoretical access to hospitals in SSA based on evidence-based time thresholds? | National health facility databases<br><br>National road networks<br><br>Gridded data on total population and women of child bearing age<br><br>National boundaries including islands |
| Chapter 3 | Is there a relationship between geographic access to hospitals for women of child bearing age and maternal and neonatal mortality? | National level access quotients from Chapter 2<br><br>National level determinants of maternal and neonatal mortality in Section 1.6.3 |
| Chapter 4 | Which hospitals in Kenya provide caesarean sections and care for newborns with very low birthweight?<br><br>What is the level of geographic access to these hospitals in Kenya? | Service availability assessments<br><br>Enumeration area population data<br><br>Road network<br><br>Geospatial covariates: land use, elevation, rainfall data |
| Chapter 5 | What is the relationship between the access in Chapter 5 to outcomes?<br><br>What are the implications? | County and individual level quotients of access<br><br>County and individual level quotients of determinants of outcomes in Section 1.6.3 |
| Chapter 6 | What is the potential of the hospital database?<br><br>What is the potential of the hospital service availability assessment?<br><br>What is the potential of the access metrics?<br><br>What are the limitations?<br><br>What are the implications for maternal and child health goals?<br><br>What knowledge does this thesis add?<br><br>What are the future research questions? | |

# Chapter 2: Access to Public Hospital Care in sub-Saharan Africa

## 2.1 Introduction

The review of HSSPs in Section 1.6.7, highlighted that first level referral hospitals provide the first point of care for essential emergency obstetric, neonatal and surgical services. In addition, international benchmarks for defining geographic access to emergency obstetric and surgical care entails ensuring 80% of populations live within 2 hours of these hospitals (Section 1.7). Several studies in SSA have defined geographic access to emergency obstetric and neonatal care (Section 1.8), but the review shows that these have been done in only 10 countries. Expansion of these studies to other countries relies on at the very least, on the availability of a mapped hospital database. This is however not available, despite recommendations for countries to develop master facility lists [WHO, 2013; MEASURE Evaluation, 2018]. In addition, previous access models have been poorly parameterised, with all assuming year-round transport availability across all roads, despite substantial evidence that transport is always likely to be only available in major roads (Section 1.9).

In this Chapter, a composite geo-coded inventory of public sector hospitals is assembled for 48 SSA countries and offshore islands. In this exercise, disparate sources are used and cross-checked using those reported in HSSPs and by the WHO. A cost distance algorithm is then implemented to delineate maximum catchment areas of 1 hour and 2 hours around each hospital. This is done by considering likely travel patterns to emergency facilities presented in the review of Section 1.9 and commonly used travel speeds along different roads. The total population and women of childbearing age (WoCBA) within the catchments are then extracted to define the extent of marginalisation in the region.

## 2.2 Methods

### 2.2.1 Assembly of the Africa hospital database

#### 2.2.1.1 Hospital definition

There is no standard definition of what a hospital is (Section 1.6.7) and in the present assembly I relied on facilities with the word 'hospital' in their names. In other instances, first level referral services such as surgical and obstetric care are provided by facilities without the term hospital attached to their names. In Mali for example, a review of the services provided at the different levels of care showed that referral health centers provided first level referral services such as basic surgical care and these were included as district hospitals. This was also the case in Gabon, where government medical centers provided the first level referral services. Conversely, there were instances where facilities which were termed hospitals were excluded. In Malawi, after a careful review of the HSSP, it was found that rural hospitals only offer basic primary level services commensurate with health centers and these were excluded.

Descriptive data were extracted for each hospital. These were the hospital name, highest level of administrative unit, ownership and where possible the coordinates. There were several hospitals especially in Ethiopia and the Democratic Republic of Congo that had no names, and they were assigned the names of the smallest administrative units. In instances where there were several hospitals in one admin unit, the hospitals were all assigned similar names, but numbers were added to differentiate them. In cases where there were duplicates, these were carefully checked, by using admin units, the coordinates or the HSSPs to merge or delete.

#### 2.2.1.2 Data abstraction

Data from different sources were used to construct country-specific public hospital lists, including those from ministries of health (MoH), health management information systems

(HMIS) and government statistical agencies. Other important data sources included the UN's Office for the Coordination of Humanitarian Affairs (OCHA), Humanitarian Data Exchange portal and international organisations such as United Nations Children's Fund (UNICEF) and World Health Organisation (WHO) that assemble facility lists for various purposes. In addition, individuals working in various MoH departments were contacted for additional sources of master health facility lists that are used for health commodity planning and resource allocation. In most countries, more than one single facility listing was available, and these were cross-checked and reconciled to ensure there were no duplications. Hospitals were selected from wider master facility lists based either on the use of the word hospital in the facility name or a level of service provision indicated in the originator lists.

The audit focused on the public sector hospitals, which provide general emergency services to the public. Identification of ownership was based on whether it was explicitly identified in a separate column or in cases where these were not available, the name was used to identify its ownership. For example, mission hospitals were those with an Evangelical/Islamic name attached to them. Private sector hospitals were excluded mainly due to the difficulty in their audit in addition to them not being widely available to the public due to cost constraints. Public hospitals were therefore defined as those managed by governments at national levels or locally at municipality (e.g. Zimbabwe, South Africa, Kenya and Tanzania), faith based (FBO) and non-governmental organisations (NGOs). In SSA, these public hospitals are often the main emergency care service providers, especially for rural populations, and are governed by national health policy guidelines and regulation. Public hospitals that focus on specialised services (for example, specific psychiatric, leprosy, ophthalmic, spinal, rehabilitative or tuberculosis facilities) were also excluded. Finally, services provided to special population groups, notably military and police service hospitals, and institutional hospitals were also excluded. The focus, therefore, were hospital services targeted at a broad range of emergency or referral care to the general population.

### 2.2.1.3 Geocoding

In some databases, the hospital listings were accompanied by longitude and latitude for each facility. In some cases, these were collected using global positioning system (GPS) devices, and these were adopted as the true coordinates. Most, however, did not have the coordinates attached and these required geo-coding using other online sources. The resources used for geocoding were; Microsoft Encarta (2009 version), Google Earth, Geonames, Fallingrain, OpenStreetMap and other national digital place name gazetteers from national education, census or statistics departments. In cases where coordinates could not be found from these resources, the coordinates were adopted as the centroids of the smallest admin units but shifted to the nearest settlement area from Google Earth. All coordinates were re-checked using Google Earth to ensure that the facilities were within the respective country and administrative boundaries of their original lists and were located on major settlements not on water or offshore.

### 2.2.1.4 Validation of the hospital numbers

To cross-reference the completeness of public hospital lists, the results were compared to the numbers reported in health sector strategic plans, and a WHO global audit of medical services undertaken in 2014 [WHO, 2014b]. The HSSPs are the documents which report country status in terms of service provision including the number of health service providers and are considered to represent the true picture of coverage. However, there may be smaller discrepancies given the differences in dates of their implementation. In 2014, the WHO department of essential health technologies conducted a baseline country survey on medical devices in 177 countries. In this exercise, ministries of health or related health institutions were contacted to complete a web-based survey, which aimed to collect information on health technologies, medical devices and equipment. As such, information collected included the number of health facilities including the different levels of care. Facilities were all categorized as either health posts, health centers, district hospitals, provincial hospitals or national referral/regional hospitals. Hospital numbers at district, provincial and national levels were therefore extracted for the comparison with the assembled database.

### 2.2.2 Mapping Road networks

Google map maker road network is a crowd-sourced initiative that provides detailed, digitized road networks for academic and humanitarian purposes. The data is not freely available, and a formal request was placed with the data provided on 3rd July 2017 in shapefile format. It contained information on the road types, administrative unit, and the average speed of travel along the roads. Road type classification including their descriptions from lowest to highest levels are shown in Table 2.1.

Table 2.1 The description of road networks as obtained from Google Maps. The table also shows how the roads were classified and some of the traffic expected across each type.

| **Road Type** | **Google Maps description** | **Reclassified** |
|---|---|---|
| Non-Traffic | Roads where cars aren't allowed to drive | Local |
| Terminal | Access road doesn't carry through traffic | Local |
| Local | Low capacity street, often residential area | Local |
| Minor arterial | Moderate capacity "collector" road that funnels traffic from local roads towards arterial roads or business areas | Tertiary |
| Major arterial | High capacity road that carries large volumes of traffic between different regions of a city | Tertiary |
| Secondary | Alternate routes to primary highways, often in rural areas | Secondary |
| Primary highway | Major roads that connect regions but do not have access restrictions | Primary |
| Limited access | Highways with some access restricted, like traffic lights and stop signs | Local |
| Controlled access | Highways with restricted access through ramps and highway separators or dividers | Local |

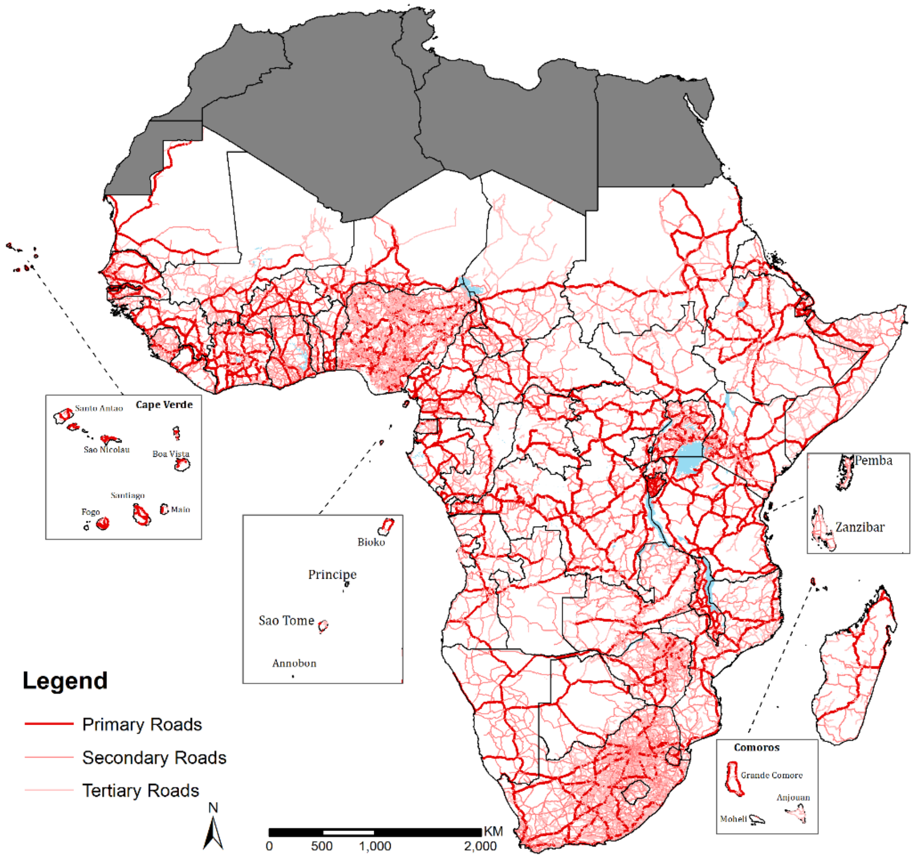
Similar to the google map data, OpenStreetMap (OSM) data was also assembled via crowd sourcing where users can freely map any area of the world in a Web 2.0 manner. OSM, established in 2004, has attracted millions of users, many of whom frequently update it from sources such as GPS traces, aerial imagery and local knowledge. OSM shapefile data is freely available and was downloaded from (http://www.openstreetmap.org/) on 10th July 2017. The description of the road layers is given in Table 2.2.

Table 2.2 OpenStreetMap road types and their description. The table also shows how the roads were classified and some of the traffic expected across each type.

| **Highway type** | **OpenStreetMap description** | **Reclassified** |
|---|---|---|
| Living street | Residential streets where pedestrians have legal priority over cars, speeds are kept very low and children are allowed to play on the street | Local |
| Service | For access roads to, or within an industrial estate, camp site, business park, car park | Local |
| Residential | Roads which are primarily lined with and serve as an access to housing | Local |
| Unclassified | Minor roads of a lower classification than tertiary, but which serve a purpose other than access to properties | Local |
| Tertiary | Smaller roads that funnel traffic to secondary roads | Tertiary |
| Secondary | Roads that often link small towns and villages | Tertiary |
| Primary | The next most important roads in a country's system and often link larger towns while also feeding trunk roads | Secondary |
| Trunk | The most important roads in a country's system that are regional and international | Primary |

Both datasets were loaded into ArcMap 10.5 (Esri, Redlands, USA) for comparison. There were similarities especially in the higher-level roads with differences observed mostly in their topology and attribute information. The OpenStreetMap data had much more topological errors such as overshoots and undershoots. An overshoot is the portion of a line digitized beyond its intersection with another line while an undershoot is the portion digitised before intersecting with another line. These were also present in the Google earth data, but to a smaller scale. Thus, where available, the google earth data was adopted as the base data and updated using the OpenStreetMap data where necessary. To ensure connectivity between the roads and location of hospitals, the two were overlaid and the existing minor gaps filled by extending the roads to hospital nodes. The roads were classified as either primary, secondary, tertiary or local roads based on their descriptions. The three major roads where motorised transport is possible are shown in Figure 2.1.

Figure 2.1 Africa road network, classified as primary, secondary and tertiary. The thickness increases from tertiary roads to primary roads. Countries not in SSA are shaded in grey while small island are shown in inset maps and not drawn to similar scales as the mainland Africa.



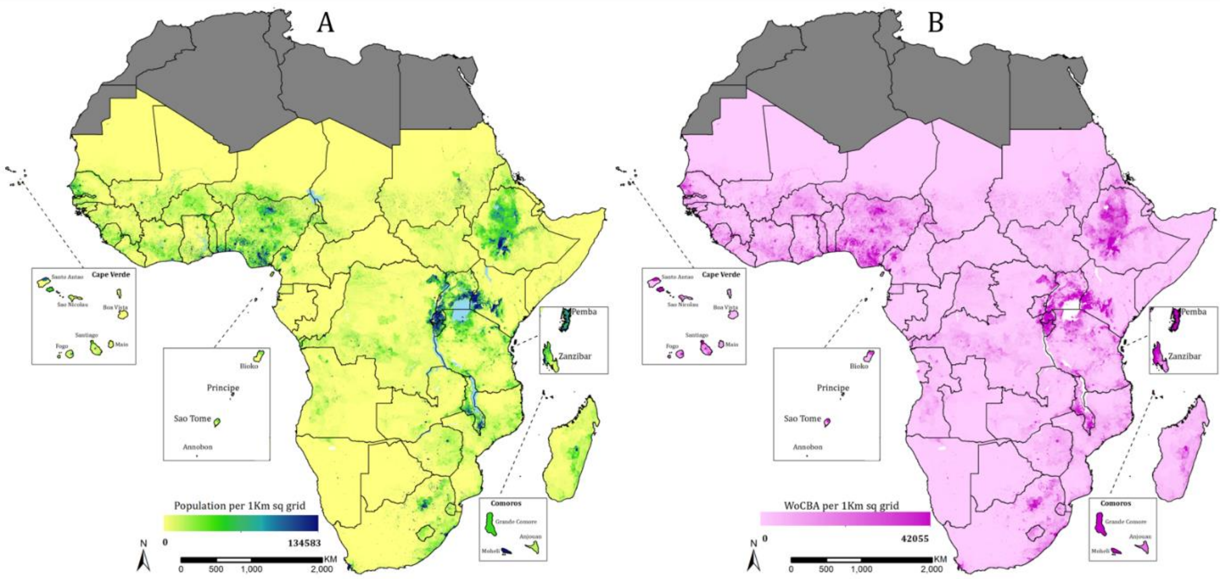

### 2.2.3 Population data

The accurate depiction of population level spatial access requires data at fine spatial resolution. Most countries, however, lack population data disaggregated to smaller admin units and where available, they are outdated. Recent approaches utilise dasymetic modelling techniques to disaggregate population from census units to grid cells [Mennis, 2009]. The simplest method used by the Gridded Population of the World (GPW) is areal-weighting technique, which proportionally allocates populations to grid cells based on the land area of each cell [Doxsey-Whitfield et al., 2015]. The accuracy of the method depends on size of the input areal unit and can be inaccurate where areal units are large. Alternatively, a set of additional datasets (such as land use, distance to roads and urbanization) which relate to how humans distribute themselves across the landscape can be used to improve modelling methods. These include the Global Rural-Urban Mapping Project (GRUMP), LandScan [Bhaduri et al., 2007] and the WorldPop [Tatem et al., 2011]. Similarly, a project run by Facebook and the Centre for International Earth Science Information Network, used high spatial resolution satellite imagery to downscale the GPW population layers to 30 m spatial resolution using artificial intelligence. Although this presents the best case scenario in terms of accuracy and resolution, it is still limited in coverage as it has only been done for 11 SSA countries [Facebook Connectivity Lab & CIESIN, 2017].

Recently, the WorldPop project outputs [Tatem et al., 2013; Sorichetta et al., 2015; Lloyd et al., 2017; Pezzulo et al., 2017] have undergone incremental advances in the methodology used to disaggregate population. Currently, the project uses census data in conjunction with a wide range of freely available spatial datasets such as roads, settlement extents, buildings, land use land cover, night-time lights and refugee camps. The model uses a random forest technique that leverages on the relationship between population distribution and the ancillary spatial datasets to produce gridded population layers at 1 Km spatial resolution [Stevens et al., 2015]. These results have demonstrated remarkable improvements in accuracy compared to other methods [Wesson et al., 2015; Lloyd et al., 2017]. The map of population distribution in Africa is shown in Figure 2.2.

To obtain distribution of women of child bearing age (WoCBA) at high spatial resolution, census summaries, census microdata or household surveys datasets were used to obtain age-sex disaggregation of the total population at highest resolution, which were the administrative units used for representing the outputs in each country. In cases where these datasets overlapped in coverage and time, the census summaries and household surveys took precedence. The data on age and sex patterns were then linked to a GIS and proportion of WoCBA defined for the sub national units. These were then multiplied to the total population surface to obtain the distribution of WoCBA at fine spatial resolutions as shown in Figure 2.2. [Tatem et al., 2013].

Figure 2.2 Distribution of A) total population with increasing values from zero (yellow) to 134583 (Blue) and B) WoCBA ranging from zero (light purple) to 42055 (dark purple). Countries not in SSA are shaded in grey while small island are shown in inset maps and not drawn to similar scales as the mainland Africa.




### 2.2.4 Geographic accessibility

Access to facilities can be defined in a number of ways and these were described in Section 1.6.1. These range from facility to population ratios, Euclidean distances, Network Analysis, Floating Catchment Area (FCA) methods and cost distance algorithms. With specific advantages and disadvantages, the usability of each method depends on a range of factors, mainly data availability. In this case, access was defined using the cost distance algorithm. The unavailability of data on service providers and population at finer geographic units makes the use of FCA method untenable in most cases. Similarly, constraints in computing power and lack of data on exact locations makes the use of network analysis difficult.

#### 2.2.4.1 Cost distance analysis

The majority of rural populations in SSA often face hardships in obtaining motorised transport at the local level, forcing them to first get to higher level road networks where motorised transport is likely to be found. Even where transport is available, local roads are often in poor conditions, a factor that can greatly impede motorised transport. Nonetheless, as shown in Chapter 1 Section 1.9, patients in need of emergency care are often likely to use motorised transport such as taxis and private vehicles, in many instances avoiding the need to call for an ambulance.

In the present analysis, the cost distance method was used because of its ability to capture multiple travel modes in a single accessibility model. In remote areas with poor road network coverage, patients were assumed to have to walk or be carried to higher level roads (primary, secondary and tertiary roads) before obtaining motorised transport to the nearest public hospital. Primary, secondary and tertiary roads were assigned speeds of 100, 50 and 30 Km per hour respectively based on previously studies [Tansley et al., 2015; Esquivel et al., 2016; Stewart et al., 2016]. Non-road areas, where motorised travel is not possible, were assigned speeds of 5 Km per hour. For sensitivity analysis, motorised speeds were varied by ± 20% of the original speeds to define an upper and lower bound of uncertainty around motorised transport, and populations within these bounds also extracted [Tansley et al., 2015; Esquivel et al., 2016].

All the datasets were initially in the World Geodetic System 1984 (WGS 1984) geographic coordinate system, which records locations using latitude and longitude, measured on a spherical earth. However, to model horizontal distances, the datasets have to be projected to a coordinate system which maps the earth onto a flat surface. Thus, for each country, the cost friction surface was projected to its own Universal Transverse Mercator (UTM) projected coordinate system. For uniformity, the WGS 1984 datum was used. The road network data was converted to raster datasets and combined with data on where populations are located to form a cost friction surface. Using the cost friction surface and location of public hospitals, the least time needed to travel to the nearest public hospital was modelled in AccessMod 5.0 at 100m spatial resolution. This resolution was chosen because it presented the best balance between accuracy and computational intensity. Catchment areas around each hospital were then created using the 1 hour and 2-hour thresholds, based on the recommendations in Section 1.7. Because this work focuses on access to emergency obstetrics and neonatal care, the proportion of the total population and WoCBA within one and two-hour catchments were then computed.

The accessibility analysis was confined within national borders, assuming populations do not cross borders to use hospitals in neighbouring countries. As shown in the HSSP review, Zanzibar has a different health sector planning process from Tanzania and its access quotient was derived separate from the mainland. For island groups; Zanzibar, São Tomé and Príncipe, Cape Verde and Comoros Islands accessibility analysis was done for each island separately and quotients national level metrics obtained by averaging those of the individual islands.

## 2.3 Results

### 2.3.1 Public hospitals

A total of 4908 hospitals were assembled from various sources, and 4893 (99.7%) were geocoded. These were drawn from a cascaded search of 100 databases covering the 47 SSA countries and islands. Zanzibar, which has an independent health system, governed by a separate ministry of health (MoH) to mainland Tanzania, was analysed separately. International organisations such as OCHA, WHO and UNICEF contributed to 33 databases. 31 databases were sourced from MoH, nine from the national malaria control programs, nine from health management information systems and eight from other ministries and government agencies such as statistical offices. Other sources included journal articles (3), web info pages (2), unpublished individual documents (2), databases from Christian health associations (2), Google Earth (1). Of the 100 sources of information, 24 were obtained from personal contacts in MoH or NGO agencies. The numbers of public hospitals, likely to be offering emergency or referral care ranged from two in São Tomé and Príncipe to 879 in Nigeria. Approximately half of the hospital data sources had either full or partial information on the longitude and latitude, the remainder (2,207) required geo-coding using Google Earth and other place name gazetteers. 15 public hospitals in Somalia (n=5) and Sudan (n=10) could not be geocoded. Figure 2.3 shows the location of geocoded public hospitals.

It was possible to compare the summaries of hospital services in 30 countries, where these were specified in both the HSSP and the WHO 2014 audit (Table 2.3). Overall, the number of hospitals audited (3203) and HSSPs (3469) were broadly comparable, but greater than those specified in the 2014 WHO audit (2518). Differences in specific countries were possibly a result of differences in years for which an HSSP was published, or inclusion/exclusion of private sector hospitals where this was not made clear in the HSSP. However, there were significant differences in the hospitals reportedly available in Ethiopia (HSSP 212; WHO 187; present audit 161); Sudan (HSSP 428; WHO 255; present audit 262) and Uganda (HSSP 160; WHO 64; present audit 121).

Figure 2.3 Location of 4893 public hospitals in SSA shown as red dots. The shaded grey areas are those countries in North Africa outside the limits of SSA. Smaller islands are shown as inset maps and are not drawn to scale of the mainland Africa.

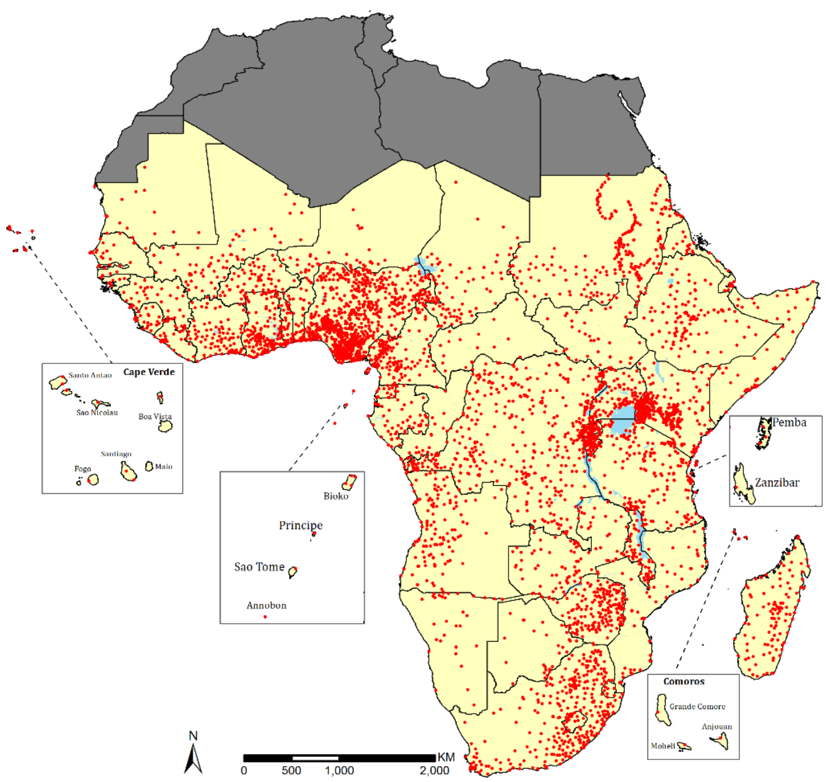


Table 2.3 Country level comparison of hospital numbers between HSSPs, the WHO and the mapped database. The references are shown in Appendix 1

| Country | No. of public hospitals (HSSP) [Refs in Appendix 1] | WHO Number of public hospitals [2014] [ref in Appendix 1] | No. Mapped/Tot public hospitals & Est. Dates | Source of mapped hospitals [Refs] |
|---|---|---|---|---|
| Angola | 209 (2012-2025) [2] | NA | 150/150 (2013) | [3,4] |
| Benin | 36 (2009-2018) [5] | 42 | 48/48 (2014) | [6,7] |
| Botswana | 26 (2011) [8] | 26 | 29/29 (2014) | [9] |
| Burkina Faso | 52 (2011-2020) [10] | 50 | 62/62 (2007) | [11,12] |
| Burundi | 69 (2016-2025) [13] | 51 | 49/49 (2014) | [14,15] |
| Cameroon | 176 (2016-2025) [16] | 170 | 184/184 (2015) | [17,18] |
| Cape Verde | NR (2012-2016) [19] | 5 | 9/9 (2012) | [20,21] |
| Central African Republic | NR (2015-2016) [22] | 22 | 20/20 (2013) | [23] |
| Chad | NR (2013-2015) [24] | 77 | 78/78 (2013) | [25,26,27] |
| Comoros | 3 (2010-2014) [28] | 5 | 3/3 (2004) | [29] |
| Congo | 31 (2007-2011) [30] | NA | 25/25 (2013) | [31] |
| Cote d'Ivoire | 85 (2013-2015) [32] | 86 | 100/100 (2013) | [33,34] |
| Democratic rep of Congo | 497 (2011-2015) [35] | 301 | 435/435 (2014) | [36,37,38] |
| Djibouti | NR (2013-2017) [39] | NA | 13/13 (2016) | [40] |
| Equatorial Guinea | NA | NA | 18/18 (NA) | [41] |
| Eritrea | 25 (2012-2016) [42] | 22 | 22/22 (2013) | [43] |
| Ethiopia | 212 (2016-2020) [44] | 187 | 161/161 (2011) | [45,46,47,48] |
| Gabon | 58 (2011-2015) [49] | 55 | 59/59 (2012) | [50,51] |
| Gambia | 5 (2012-2020) [52] | 13 | 6/6 (2015) | [53,54] |
| Ghana | 199 (2014-2017) [55] | 32 | 178/178 (2016) | [56] |
| Guinea | 41 (2015-2024) [57] | 41 | 35/35 (2015) | [58,59] |
| Guinea-Bissau | NR (2008-2017) [60] | NA | 8/8 (2017) | [61] |
| Kenya | 359 (2013-2017) [62] | 260 | 399/399 (2016) | [63,64,65,66] |
| Lesotho | 19 (2012-2017) [67] | NA | 20/20 (2012) | [68,69] |
| Liberia | 26 (2011-2021) [70] | 16 | 38/38 (2014) | [71,72] |
| Madagascar | 125 (2015-2019) [73] | 54 | 125/125 (2012) | [74,75] |
| Malawi [d] | 48 (2011-2016) [76] | 65 | 56/56 (2016) | [77,78,79,80] |
| Mali [e] | 70 (2014-2023) [81] | 70 | 76/76 (2015) | [82,83] |
| Mauritania | 13 (2012-2020) [84] | 20 | 18/18 (2014) | [85] |
| Mozambique | 51 (2001-2010) [86] | NA | 61/61 (2013) | [87,88,89] |
| Namibia | 33 (2010-2020) [90] | 34 | 35/35 (2009) | [91,92,93] |
| Niger | 45 (2013-2020) [94] | 54 | 41/41 (2014) | [95,96] |

Table 2.3 continued…

| Country | No. of public hospitals (HSSP) [Refs in Appendix 1] | WHO Number of public hospitals [2014] | No. Mapped/Tot public hospitals & Est. Dates | Source of mapped hospitals [References] |
|---|---|---|---|---|
| Nigeria | 950 (2010-2015) [97] | NA | 879/879 (2012) | [98] |
| Rwanda | 45 (2012-2018) [99] | NA | 47/47 (2016) | [100,101] |
| São Tomé and Príncipe | NR (2012-2015) [102] | NA | 2/2 (2011) | [103] |
| Senegal | 20 (2009-2018) [104] | 22 | 29/29 (2012) | [105] |
| Sierra Leone | 41 (2010-2015) [106] | NA | 32/32 (2015) | [107,108] |
| Somalia | 55 (2013-2016) [109,110,111] | NA | 74/79 (2015) | [112,113,114,115] |
| South Africa | 315 (2015 - 2020) [116] | 356 | 327/327 (2014) | [117] |
| South Sudan | 37 (2012-2016) [118] | NA | 40/40 (2015) | [119] |
| Sudan | 428 (2003-2027) [f] [120] | 255 | 262/272 (NA) | [121] |
| Swaziland | 8 (2014-2018) [122] | 4 | 7/7 (2010) | [123] |
| Tanzania (Mainland) | 208 (2015-2020) [124] | NA | 210/210 (2015) | [125] |
| Togo | 44 (2012-2015) [126] | 41 | 38/38 (2013) | [127,128,129,130,131] |
| Uganda | 160 (2015-2020) [132] | 64 | 121/121 (2017) | [133,134,135] |
| Zambia | 109 (2011-2015) [136] | 57 | 91/91 (2012) | [137] |
| Zanzibar | 6 (2007-2011) [138] | NA | 4/4 (2013) | [139,140] |
| Zimbabwe | 182 (2016-2020) [141] | 65 | 169/169 (2009) | [142,143,144,145] |

Hospital data was available for the 48 countries/regions including islands, all of which had road networks from OpenStreetMaps. On the other hand, there was no Google maps road network data for Guinea Bissau, Lesotho, South Africa, Zambia and Zimbabwe. In countries where data from both sources was available, conflating was a challenge, owing to the different schemas, domains and standards that characterise them. Just like in many Volunteered Geographic Information Systems, the geometric quality, consistency and completeness of either of the datasets could not be ascertained, and both had to be compared against one another.

### 2.3.2 Accessibility to hospital care

The accessibility analysis was conducted for 48 countries and islands in SSA. Results show that 704 million (71%) people and 164 million (72%) WoCBA were living within 2 hours of the nearest public hospital across the 48 SSA countries or offshore islands. 526 million people (53%) and 124 million WoCBA (54%) were living within 1 hour of a public hospital in SSA (Table 2.4). Conversely, the most geographically marginalized in 2015 were 286 million (29%) people and 64 million (28%) WoCBA who were more than two hours from emergency public hospital care. Populated areas with more than one person per $Km^2$, but outside a two-hour motorised travel to public hospital care, are shown in Figure 2.4 to highlight areas in need of greatest health service accessibility.

Geographic accessibility varied between countries, ranging from less than 25% of the population within two hours of a public hospital in South Sudan to over 90% in Nigeria, Malawi, Kenya, Cape Verde, Swaziland, South Africa, Burundi, Comoros, São Tomé and Príncipe and Zanzibar. Eight countries had less than 50% of the population within two hours' travel-time of a public emergency care hospital: South Sudan, Mauritania, Eritrea, Niger, Sudan, Madagascar, Chad and Central African Republic. Several large countries such as South Sudan, Mauritania, Democratic Republic of Congo, Mozambique and Zambia have poor access compared to smaller countries like Cape Verde, Zanzibar and São Tomé and Príncipe (Table 2.4). There were notable exceptions to this, however, with large countries such as Nigeria, Kenya and South Africa having more than 90% of their respective population living within 2 hours of a hospital.

Figure 2.4 Hospital accessibility from cost distance analysis where dark green represents areas within 1 hour of a public hospital, while medium green shows areas more than 1 hour but less than 2 hours of the nearest hospital. Areas with at least 1 person per Km$^2$

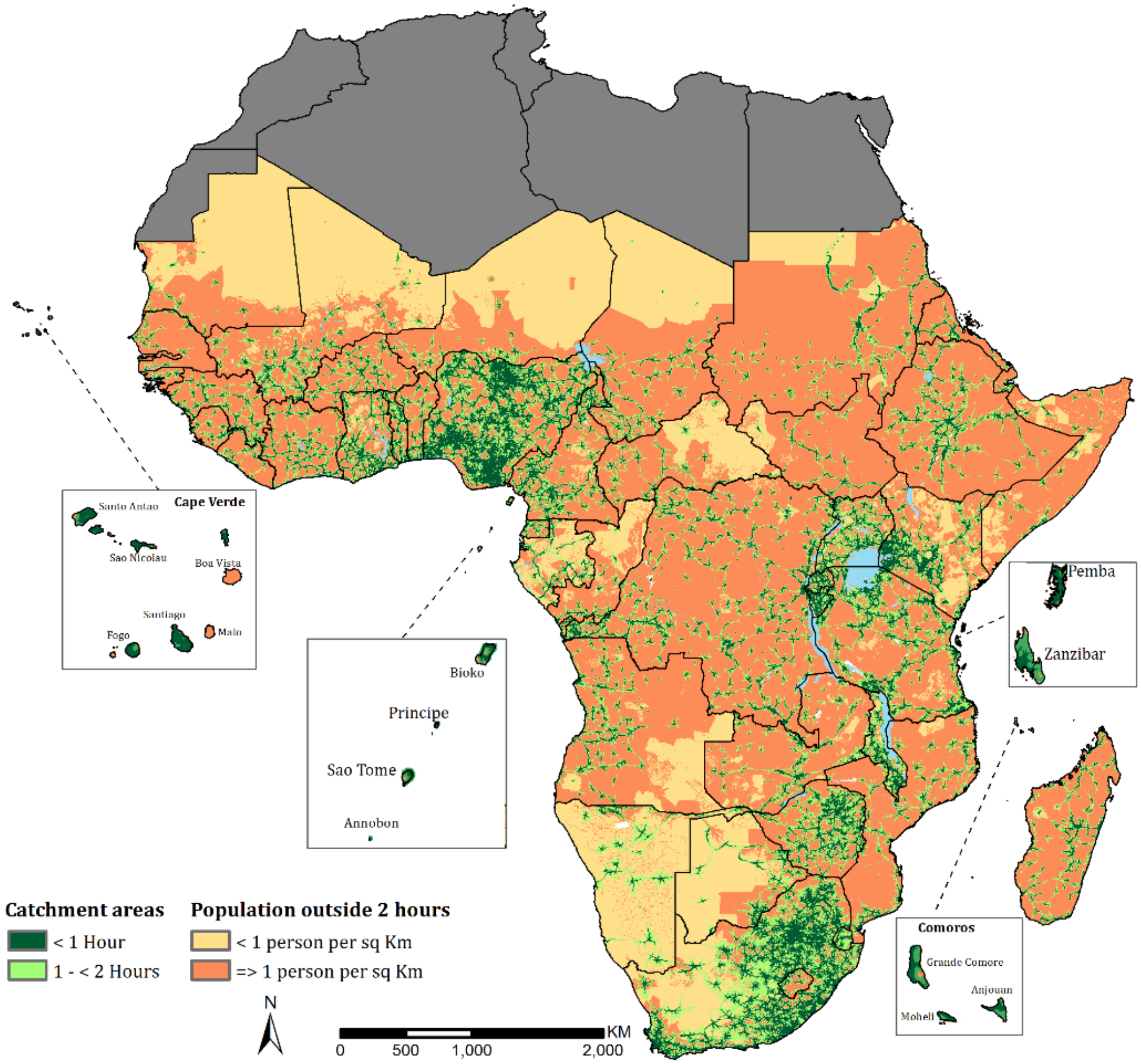



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Table 2.4 National summaries of access quotients with uncertainty intervals (UI) across 47 SSA countries and Zanzibar

| **Country** | **Country Code (ISO3)** | **Total population (2015)** | **% Pop within 1 hour (UI)** | **% Pop outside 2 hours (UI)** | **Total WoCBA (2015)** | **% WoCBA outside 2 hours (UI)** |
|---|---|---|---|---|---|---|
| Angola | AGO | 21,811,453 | 52·4 (51·1-53·5) | 36·9 (35·5-39·0) | 5,489,490 | 37·3 (35·8-40·0) |
| Benin | BEN | 10,880,616 | 55·3 (52·3-57·7) | 23·3 (20·9-27·2) | 2,136,501 | 23·7 (21·3-27·6) |
| Botswana | BWA | 2,258,625 | 64·7 (62·6-66·7) | 23·3 (20·9-27·5) | 622,953 | 23·3 (20·9-27·5) |
| Burkina Faso | BFA | 18,069,713 | 35·6 (33·0-37·3) | 46·9 (44·8-50·0) | 4,091,918 | 45·2 (43·1-48·2) |
| Burundi | BDI | 11,162,902 | 72·3 (69·0-74·7) | 4·3 (3·9-5·0) | 2,515,577 | 4·2 (3·8-4·9) |
| Cameroon | CMR | 23,342,359 | 65·6 (63·3-67·2) | 17·4 (16·4-18·8) | 5,230,085 | 17·1 (16·3-18·7) |
| Cape Verde | CPV | 488,986 | 82·5 (78·9-84·9) | 6·6 (6·6-6·6) | 132,377 | 7·0 (6·9-7·0) |
| CAR | CAF | 4,898,576 | 34·0 (32·4-35·6) | 51·5 (47·3-55·6) | 1,192,470 | 51·6 (47·4-55·7) |
| Chad | TCD | 14,022,236 | 30·9 (32·4-32·4) | 53·1 (51·4-55·7) | 2,973,342 | 53·2 (51·4-55·8) |
| Comoros | COM | 697,609 | 56·1 (47·0-64·0) | 3·4 (2·4-5·8) | 173,474 | 3·5 (2·5-6·0) |
| Congo | COG | 4,584,395 | 63·8 (62·8-64·5) | 27·7 (26·6-29·1) | 1,186,661 | 27·8 (26·7-29·1) |
| Côte d'Ivoire | CIV | 22,699,552 | 48·1 (46·1-49·7) | 34·4 (32·9-36·8) | 5,659,963 | 34·4 (32·9-36·8) |
| DRC | COD | 72,001,218 | 38·6 (36·5-40·4) | 46·3 (44·0-49·2) | 14,330,432 | 46·2 (43·9-49·2) |
| Djibouti | DJI | 870,713 | 76·0 (74·0-76·7) | 16·7 (16·1-17·6) | 211,489 | 17·0 (16·4-17·9) |
| Equatorial Guinea | GNQ | 824,276 | 48·8 (44·2-52·2) | 24·2 (22·2-27·4) | 188,338 | 24·2 (22·3-27·3) |
| Eritrea | ERI | 5,210,651 | 26·3 (24·6-28·0) | 57·4 (55·5-59·8) | 1,345,007 | 55·7 (53·9-58·0) |
| Ethiopia | ETH | 99,337,653 | 26·1 (23·0-28·6) | 49·3 (45·5-54·3) | 22,721,668 | 49·3 (45·4-54·2) |
| Gabon | GAB | 1,628,849 | 78·6 (77·9-79·1) | 16·4 (15·9-17·0) | 397,063 | 16·4 (16·0-17·1) |
| Gambia | GMB | 1,950,904 | 62·7 (59·5-65·3) | 28·5 (28·1-29·3) | 411,783 | 29·3 (28·9-30·0) |
| Ghana | GHA | 27,098,194 | 67·9 (65·1-69·8) | 13·8 (12·8-15·5) | 7,126,334 | 13·9 (12·8-15·6) |
| Guinea | GIN | 12,546,646 | 43·9 (41·7-45·7) | 37·3 (35·0-40·3) | 2,520,496 | 37·2 (34·9-40·2) |
| Guinea-Bissau | GNB | 1,745,803 | 41·7 (39·7-43·5) | 38·5 (34·6-44·4) | 429,740 | 38·4 (34·5-44·3) |
| Kenya | KEN | 45,737,778 | 78·8 (76·2-80·6) | 7·1 (6·5-8·1) | 11,243,809 | 7·1 (6·4-8·0) |
| Lesotho | LSO | 2,136,640 | 34·3 (31·9-36·3) | 43·3 (40·8-46·4) | 570,583 | 43·3 (40·9-46·5) |
| Liberia | LBR | 4,451,499 | 43·0 (40·8-44·6) | 38·5 (36·9-40·7) | 1,090,502 | 38·5 (36·9-40·6) |
| Madagascar | MDG | 24,120,532 | 30·5 (28·7-31·8) | 53·4 (52·0-55·8) | 5,262,812 | 53·3 (51·9-55·7) |
| Malawi | MWI | 17,207,197 | 65·3 (58·6-70·1) | 7·2 (5·5-10·2) | 3,938,576 | 7·2 (5·5-10·2) |
| Mali | MLI | 17,619,152 | 46·2 (40·3-46·2) | 36·2 (33·3-40·6) | 3,258,813 | 35·3 (32·4-39·7) |

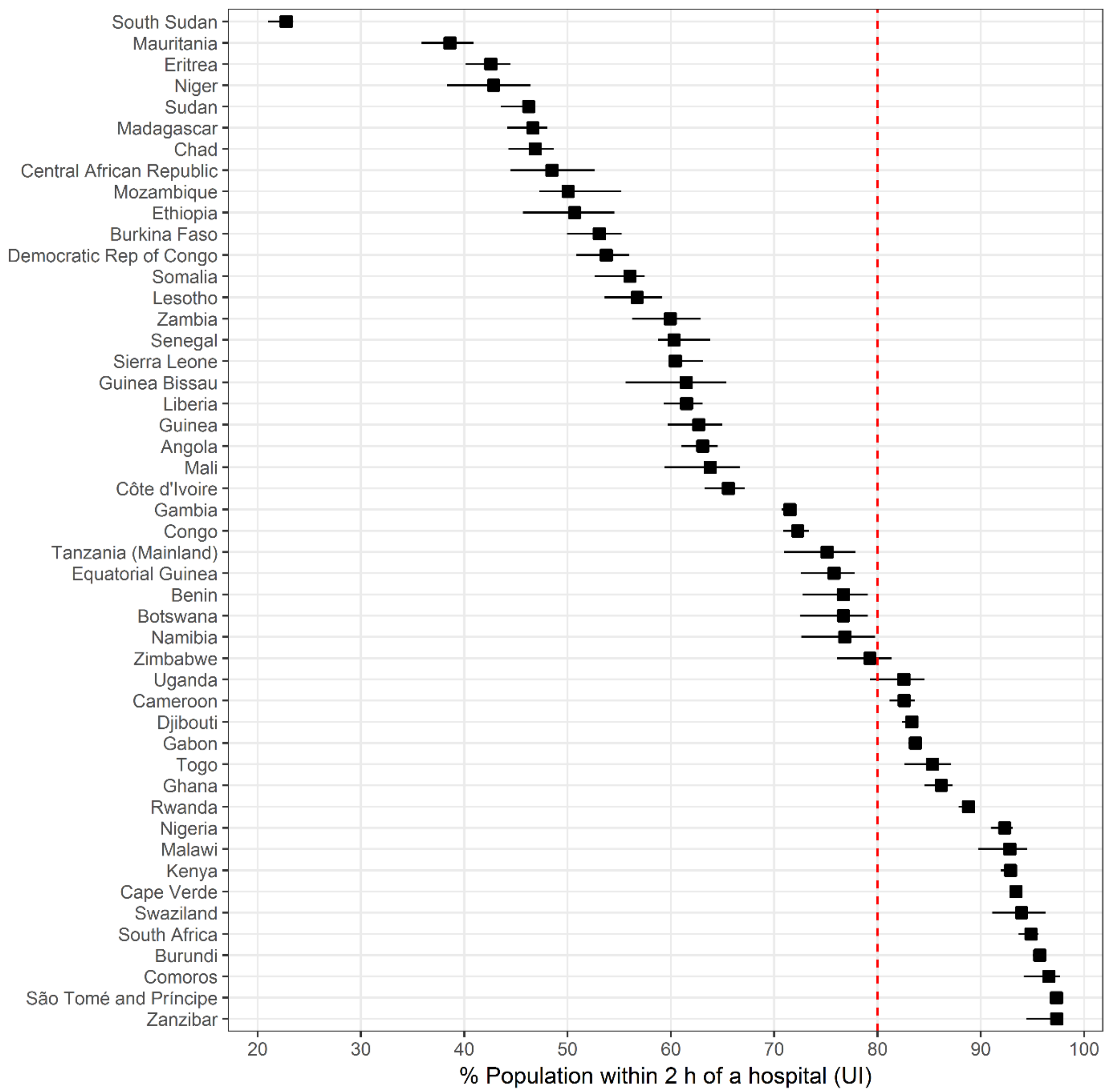
Table 2.4 Continued…

| **Country** | **Country Code (ISO3)** | **Total population (2015)** | **% Pop within 1 hour (UI)** | **% Pop outside 2 hours (UI)** | **Total WoCBA (2015)** | **% WoCBA outside 2 hours (UI)** |
|---|---|---|---|---|---|---|
| Mauritania | MRT | 4,026,075 | 29·0 (28·1-30·0) | 61·4 (59·1-64·1) | 880,617 | 61·4 (59·1-64·2) |
| Mozambique | MOZ | 27,673,736 | 32·6 (31·2-35·8) | 49·9 (44·8-52·7) | 6,431,717 | 49·8 (44·6-52·5) |
| Namibia | NAM | 2,461,440 | 55·0 (51·8-58·6) | 23·2 (20·2-27·4) | 644,284 | 23·2 (20·3-27·5) |
| Niger | NER | 19,805,985 | 25·2 (23·5-26·9) | 57·2 (53·6-61·7) | 3,376,284 | 57·1 (53·5-61·6) |
| Nigeria | NGA | 182,178,061 | 78·0 (74·4-80·4) | 7·7 (6·9-9·0) | 43,659,033 | 8·5 (7·8-10·1) |
| Rwanda | RWA | 11,585,862 | 62·0 (59·5-63·7) | 11·2 (10·6-12·1) | 2,793,168 | 11·3 (10·7-12·2) |
| STP | STP | 186,623 | 85·1 (83·6-86·1) | 2·7 (2·4-3·1) | 43,894 | 2·7 (2·5-3·2) |
| Senegal | SEN | 14,967,332 | 42·6 (41·7-44·9) | 39·7 (36·2-41·2) | 3,583,623 | 39·6 (36·1-41·1) |
| Sierra Leone | SLE | 6,418,015 | 40·5 (39·8-42·2) | 39·6 (36·9-39·1) | 1,537,021 | 39·6 (37·0-39·2) |
| Somalia | SOM | 10,688,048 | 43·1 (42·2-44·5) | 44·0 (42·5-47·4) | 2,179,717 | 42·3 (40·9-45·6) |
| South Africa | ZAF | 54,345,833 | 83·3 (76·7-80·7) | 5·2 (4·4-6·3) | 15,021,723 | 5·2 (4·5-6·4) |
| South Sudan | SDS | 12,347,507 | 14·0 (12·3-13·7) | 77·2 (76·5-79·0) | 2,786,192 | 77·3 (76·6-79·0) |
| Sudan | SDN | 40,249,394 | 30·6 (27·5-31·5) | 53·8 (53·2-56·5) | 9,346,646 | 53·7 (53·1-56·3) |
| eSwatini | SWZ | 1,285,392 | 54·9 (47·7-64·1) | 6·1 (3·7-8·9) | 289,274 | 6·1 (3·8-9·0) |
| Tanzania | TZA | 53,265,074 | 50·2 (45·4-53·9) | 24·9 (22·1-29·0) | 12,585,409 | 24·8 (22·1-29·0) |
| Togo | TGO | 7,304,010 | 63·7 (59·5-66·6) | 14·7 (12·9-17·4) | 1,588,063 | 14·8 (13·3-17·7) |
| Uganda | UGA | 39,032,494 | 52·3 (48·0-55·8) | 17·5 (15·5-20·7) | 7,979,425 | 17·5 (15·5-20·8) |
| Zambia | ZMB | 16,218,094 | 39·8 (37·2-42·0) | 40·1 (37·1-43·7) | 3,699,046 | 40·0 (37·0-43·7) |
| Zanzibar | - | 1,579,927 | 71·9 (68·9-74·9) | 2·7 (2·0-5·6) | 376,652 | 2·6 (1·9-5·5) |
| Zimbabwe | ZWE | 15,604,001 | 55·3 (52·0-58·0) | 20·7 (18·6-23·9) | 3,453,496 | 21·5 (19·4-24·6) |
| Total | | 990,627,630 | 53·1 (49·9-55·0) | 29·0 (27·1-31·5) | 228,707,538 | 28·2 (26·4-30·8) |

**Footnote:** UI computed by adding and subtracting 20% of travel speeds

Only 17 countries met the international recommendation of more than 80% of the population within two hours of a hospital. Overall, 17 countries had more than 80% of their respective populations within 2 hours of a public hospital (Figure 2.5).

Figure 2.5 Proportion of population living within 2 hours of a hospital in 2015 and their respective uncertainty intervals (UIs). The red line distinguishes between countries which have 80% of their respective populations within 2 hours of a hospital and those yet to meet this threshold. This is similar for WoCBA too.



## 2.4 Discussion

This has been the first time a single Pan-African, geo-coded database of public hospitals for 48 countries and islands has been assembled. Assessment of geographic accessibility shows significant variations at both national and sub-national levels. The results show that 29% of the population and 28% of the WoCBA are marginalised from emergency medical, obstetric, and surgical care, living more than two hours to the nearest public hospital. Assuming all hospitals have surgical care capacity, only 17 countries meet the threshold to have more than 80% of their population living within two hours of emergency hospital care. Smaller countries, and islands, have proportionately better access to hospital services, and in several large countries such as Democratic Republic of Congo, Ethiopia, Mauritania, Mozambique and Zambia, more than 40% of the population live more than two hours from a public hospital. However, several exceptions can be noted, where large countries such as South Africa, Nigeria and Kenya have better access quotients, compared to smaller countries like Eritrea and Lesotho.

Health facility lists in Africa are fragmented, only 31 (31%) of original sources were from MoHs, and a diverse list of sources, especially from other governmental and international agencies, were required to provide a more comprehensive understanding of hospital care. The accuracy and completeness of this resource requires further country and regional level efforts, while this initial database serves as a useful entry point to future hospital censuses in Africa. Countries should therefore focus on developing master facility lists, complete with coordinates for better accessibility analyses. The importance of having master facility lists extends beyond accessibility and is a key resource for monitoring services provided to the population.

Similar spatial interrogation of accessibility has been done in specific African countries. A continental wide analysis using the same hospital numbers assembled in this Chapter estimated that 7.5% of SSA population live outside two hours of a surgical hospital [Juran et al., 2018]. This is 13% higher than the numbers estimated in this Chapter and can mainly be attributed to the high spatial resolution (1km) the study used compared to the 100m used in this Chapter. Increasing spatial resolutions of analysis is likely to overestimate accessibility as finer heterogeneity is less captured. In Zambia, analysis of spatial access to surgical facilities found that 15% of the population live more than 2 hours from a surgical facility, compared to results herein which shows that 40% do not have access within the same time band [Esquivel et al., 2016]. This can be attributed to two reasons. First, the Zambia study used 103 surgical facilities, in this case only 91 were used. Secondly, they assumed that motorised transport is available at all roads, a factor which may overestimate accessibility. A similar study in Ghana used 95 hospitals to show that 77% of the population has live within two hours of a surgical hospital. This was also higher than the 67% estimated in the present work and may again be due to how parameters in the accessibility models are defined [Stewart et al., 2016]. These factors highlight the importance of accurately accounting for likely transportation patterns including where motorised transport may be available. It was however not possible to compare results of this Chapter to those in other studies summarised in Section 1.8, given that they either used straight line distances to measure access, were conducted at smaller spatial scales or in countries outside SSA. This study, nonetheless, improved on previous analyses by accounting for like transportation patterns.

The private sector plays a crucial role in achieving UHC [Mackintosh et al., 2016; McPake & Hanson, 2016]. This sector, however, remains poorly enumerated even at national levels. In this audit, private hospital data was only available for 21 countries, with little or no data on their coverage from all the HSSPs or the WHO to enable validity assessments. This supports previous audits in SSA, that have found it difficult to enumerate the scale and coverage of the private sector [Noor et al., 2009; Macharia et al., 2017]. Future hospital service censuses and audits must include the private sector as these services compete with public sector services especially in the urban areas as the private sector also plays a key role in attaining UHC. In addition crowdsourcing initiatives such as the healthsites.io that was set up to map all health facilities globally and make the data available freely [Saameli et al., 2018]. If implemented then this will be a key initiative in mapping the private sector.

### 2.4.1 Limitations

This analysis had several limitations. The services provided at each of the mapped 4,908 public hospitals could not be ascertained. Given the recorded deficiencies of service availability at hospitals in terms of providing EmONC, the results presented here may over estimate accessibility. This makes it difficult to compare hospitals in different countries. The actual level of service provision should in theory be available from national Service Availability and Readiness Assessment (SARA) and Service Provision Assessment (SPA) surveys, however these are often only sampled facilities. Both sources aim to assess the services available in facilities and readiness to provide a range of services, with additional modules for collecting management practices. To date, SARA surveys have been conducted in 11 SSA countries, while SPA surveys have been done in 10 SSA countries. To improve availability of data from the two sources and also to capture strengths of both sources of data, plans are underway by development partners to transition to harmonised health facility assessments, with Kenya chosen as the pilot country [WHO, 2014c]. In addition, availability of routinely collected data from the DHIS2 which, provides timely reporting rates can be used to identify the services available in hospitals.

It was not possible to evaluate the efficiency, timeliness and abilities of referral transport systems in each country with adequate precision at a continental scale. It was difficult to account for frequency of transport services on secondary to main roads connected to hospital locations and the precise transport speeds. As shown in Section 1.9, these can vary at more localised level. For example, despite motorised transport being the most sought after means of transport to emergency care, reaching points where motorised transport is available varies between communities.

The AccessMod model implemented herein was also limited in a number of ways. The highest possible resolution was 100m, and although this is an improvement from other previous continental or global assessments of spatial accessibility [Alegana et al., 2018; Weiss et al., 2018], this may still overestimate access as even smaller roads are assigned this resolution. Secondly, when performing the neighbourhood analysis in the least cost path assessment, AccessMod only considers the surrounding eight pixels of any cell of interest. However, it has been shown that connecting cells in 16 directions may increase accuracy of the calculations [van Etten, 2017]. Thirdly, other transportation dynamics such as changes in weather patterns were also not accounted for.

Limitations of the population data may have also affected the estimates of accessibility. Mainly, WorldPop uses several covariates in the prediction including proximity to roads and health facilities [Alegana et al., 2015; Stevens et al., 2015]. In the present analysis, this may have introduced circularity, which causes overestimation of accessibility given that proximity to facilities and roads are key inputs in the accessibility model. At a continental scale, it was not possible to correct for this, and will be addressed in Chapter 4. Another limitation is the inability to account for population dynamics such as migration patterns or changing age structures. Such datasets are not available, and where they are, they are only defined at national levels.

Other factors such as education, ability to pay and cultural differences may affect physical accessibility [Grimes et al., 2011; Kyei-Nimakoh et al., 2017]. Recently, it has been shown that these factors can affect estimates of accessibility, although data availability may still pose significant challenge towards their inclusion [Ouma et al., 2017].

### 2.4.2 Summary

Ensuring populations have access to emergency obstetric and neonatal care can significantly reduce maternal and neonatal mortality. Key towards understanding where gaps in accessing emergency obstetric care is in highlighting population's most distal from these services. Previously, this was mainly limited by lack of geocoded facility lists and poorly defined metrics of access. To fill these gaps, this Chapter aimed to assemble the first geo-coded database of public hospitals in SSA and use it to define access to hospital services in SSA. Results show that access is poor within and between countries with approximately 29% of WoCBA living more than two hours from the nearest hospital. Most importantly, areas of high and low coverage were identified at local levels (100m by 100m) and national levels, and identification of gaps can be crucial in designing strategies for improving accessibility. In addition, an understanding of how access relates to outcomes such as maternal and neonatal mortality remains inadequate (Section 1.10.1), and this relationship will be further explored in Chapters 3 and 4.

The limitations of this Chapter include the assumption that hospitals offer CEmONC services and the parameterising the access model with appropriate population surfaces. Addressing these challenges requires more localised assessments for a single country and Chapter 5 will use Kenya as an exemplar of how geographic access to CEmONC hospitals can be defined in an improved way, by conducting a service availability assessment, using population surfaces that reduce circularity and an access model that models neighbourhood in an improved sense while accounting for other dynamics of access such as weather patterns.

The following paper has been published from this work;

**Ouma PO**, Maina J, Thuranira PN, Macharia PM, Alegana AA, English M, Okiro EO, Snow RW (2018). Access to emergency hospital care provided by the public sector in sub-Saharan Africa in 2015: a geocoded inventory and spatial analysis. *Lancet Global Health,* **6**: e342–e350 [PMID: 29396220] [PMCID: PMC5809715].

The hospital list has been published from this work;

**Ouma PO**; Okiro, EA; Snow, RW, 2017, Sub-Saharan Public Hospitals Geo-coded database"; https://doi.org/10.7910/DVN/JTL9VY, Harvard Dataverse, V1

Two blogs have also been published from this Chapter;

**Ouma PO** & Okiro EA. People across Africa have to travel far to get to a hospital. We worked out how far, September 2018; https://theconversation.com/people-across-africa-have-to-travel-far-to-get-to-a-hospital-we-worked-out-how-far-102585

**Ouma PO** & Okiro EA. África: algunas soluciones para aminorar el largo camino al hospital, September 2018; https://theconversation.com/africa-algunas-soluciones-para-aminorar-el-largo-camino-al-hospital-103391

# Chapter 3: Relationship Between Geographic Access to Hospital Care and Maternal and Neonatal Mortality in sub-Saharan Africa.

## 3.1 Introduction

Access to healthcare can be impeded by factors such as delays in deciding to seek care, delays in accessing care (geographic) and delays in getting services once at the facility. In Chapter 2, a spatial database of hospitals was assembled and used to define geographic access to hospitals that, in theory, should provide CEmONC in SSA. In SSA, where services are scarce, and majority of the population live in sparsely populated rural areas, the influence of geographic access often overrides the other factors. International benchmarks for defining geographic access to CEmONC services have been established, yet, as Section 1.10 shows, there is a paucity of studies investigating the role of access to CEmONC care on maternal mortality. There have been few investigations on whether increasing population within 2 hours of a CEmONC hospital corresponds to reduced maternal mortality. In addition, some potentially useful covariates were either missed or not used as confounders with some missing potentially useful covariates (Section 1.6.1).

The aim of this Chapter is to assess the relationship between geographic access to hospital care and maternal and neonatal mortality, using national level estimates as units of analysis. This relationship is, however, not straight forward as shown in the conceptual frameworks in Figure 1.7 and Figure 1.10, with other factors confounding the relationship. This Chapter begins with a brief description of the two main variables: Maternal and neonatal mortality (Section 1.6.1) and geographic accessibility (Section 2.2.4). The additional covariates have been described in Section 1.6.3. Methods used are described in Section 3.2 with the results section presented in Section 3.3. Finally, their implications for the observed relationships are discussed in Section 3.4. The primary outcome is geographic access to hospitals and was only representative to 2015, thus all variables and outcomes were extracted to the same year or in other cases, years close to 2015.

## 3.2 Methodology

### 3.2.1 Maternal and neonatal mortality data for 2015

The outcome variables were both MMR and NMR and were obtained from the Institute for Health Metrics and Evaluation (IHME), based on criteria described in Sections 1.6.1.3 and 1.6.2.1 [GBD, 2017]. MMR represents the number of deaths from any cause related or aggravated by pregnancy occurring during the pregnancy, childbirth or within 42 days of termination of pregnancy, for every 100,000 livebirths. NMR corresponds to the number of newborn deaths that occur within the first 28 days of life per 1,000 livebirths. Details of how both outcomes were computed are described in detail in Section 1.6.2. The 2015 estimates were chosen because they correspond to the year when the accessibility metrics were computed.

### 3.2.2 Geographic access to public hospital care

National level estimates of the proportion of WoCBA living within 2 hours of a hospital were modelled in Chapter 2 for 47 SSA Countries (Table 2.4). This identified the subset of WoCBA who would face increased difficulty in using hospital services when required, i.e. those living outside a two-hour window. This metric only captures the physical aspects of access to healthcare and other variables were included to capture confounders of the relationship between geographic access to hospital care and both MMR and NMR. The accessibility quotient for Tanzania mainland was combined with Zanzibar because neither of the other variables or MMR provided separate estimates for the two geographies.

### 3.2.3 Selection of confounders

The conceptual framework in Section 1.6.1 illustrates the pathways through which different variables affect maternal and neonatal mortality in addition to confounders of distance to care. Confounders were selected as those variables which affect both distance to hospital care and mortality thus causing a spurious association. The variables which were used in modelling MMR and NMR by IHME (Fertility rates, years of education, neonatal mortality, HIV deaths, antenatal care attendance (ANC), skilled birth attendance (SBA), hospital beds per 1,000 populations, malnutrition, lag distributed income and prevalence of obesity) were excluded in the analysis to avoid circularity. Confounders selected from the conceptual frameworks in Figure 1.7 for MMR and Figure 1.10 for NMR were poverty, health workforce, adolescent fertility, physician workforce density, risk of catastrophic expenditure for surgery, proportion of urban population and fragility.

Poverty was selected because it limits ability to pay for transportation costs or the services once at the facility with this strong association shown in several studies Table 1.8. Thus, it has an influence on both proximity to hospitals and has a direct impact on both MMR and NMR. Catastrophic expenditure was selected because it is a measure of effectiveness of overall health system to make payments for both direct and indirect costs of critical services affordable regardless of the income inequality. Proportion of population living in urban areas was also used given that urban areas often have advantages in terms of proximity to hospitals, in addition to improved access to interventions such as SBA, ANC and contraceptive use and other determinants of maternal and newborn mortality such as access to water and sanitation. Political instability can also affect ability to get to hospitals in addition to ability to obtain crucial maternal and newborn services thus serving as a confounder. In addition, highly fragile areas are likely to have a higher risk of mortality. Areas with high density of health workforce are also likely to have services closer and while skilled health service providers are also key in prevention of maternal and newborn deaths. However, it was not possible to obtain data on nurses, clinical officers or medical specialists and only density of medical officers was used.

Variables that are on the causal pathway such as contraceptive use or those that may be affected by reverse causality such as exclusive breastfeeding in the case of NMR were not included as potential confounders. Contraceptive use for example affects parity or fertility rates (which are included as confounders), while also being significantly driven by educational attainment and was therefore excluded.

### 3.2.4 Data exploration

#### 3.2.4.1 Outlier detection

One tool commonly used in identifying outliers is the boxplot, which plots the median and spread of the data or the Cleveland dotplot [Zuur et al., 2010]. A dotplot is a graph in which the row number of an observation is plotted against the observed value ensuring that points sticking out on the right hand, or left-hand side are detected and evaluated. If outliers do exist it is important to check the original data for potential errors. In this study, the dotplot was used to detect outliers and the violin plot used to visualise the spread of the data.

#### 3.2.4.2 Exploring the crude linear relationships between access and outcomes

The application of a linear model assumes a linear relationship between the dependent and independent variables [Kirkwood & Sterne, 2010]. The primary aim of this section was to determine the crude (bivariable) relationship between access and both maternal and neonatal mortality. In addition, the assessment was repeated for each confounding variable. Physician workforce displayed potential nonlinear relationship with MMR and the possibility of using suitable transformations was explored including using log, square and fractional polynomials [Royston & Altman, 1994].

### 3.2.5 Multivariable adjusted models

Development of the adjusted multivariable model aimed to control for other confounders when relating access with outcomes. In the first step, poverty and log adjusted physician workforce were included a priori because of their importance in explaining the variation in maternal and neonatal mortality. For the remaining variables, regularization technique, using the elastic net regression was used to select those that would best define the model. A brief description of regularization is provided.

Regularization technique is a form of regression that constrains/shrinks (regularizes) the coefficient estimates towards zero in the process accounting for model complexity. It thus allows for learning of more complex or flexible models thus avoiding problems of overfitting. There are three regularization techniques. Ridge, Lasso and Elastic Net. All methods use a constraining term (lambda) which minimizes coefficients (shrinkage). Shrinkage results to lower variance and in turn a lower error value and thus ridge regression decreases the complexity of a model.

*a) Ridge regression*

Ridge regression uses L2 regularization which adds a penalty term to the OLS equation.

$$\lambda\sum_{j=0}^{p}\omega_j^0 \qquad \text{Equation 3.1}$$

where $\omega$ is the sum of the square of coefficients and $\lambda$ is the regularization parameter.

Thus if $\lambda$ is set to zero then the equation reverts to a basic OLS but if greater than zero then a constraint is added to the coefficients.

*b) Lasso regression*

Lasso regression (stands for Least Absolute Shrinkage and Selection Operator) uses the L1 penalty term. The L1 penalty is equal to the absolute value of the magnitude of the coefficients and is given by:

$$\lambda\sum_{j=0}^{p}|\omega_j| \qquad \text{Equation 3.2}$$

The parameters are similar to the ones in ridge regression. However, given a suitable lambda value, the lasso can drive some coefficients to zero. As such, this method can eliminate some variables and give a set of predictors that helps in mitigating against multicollinearity and model complexity. Thus, those not shrunk to zero can be treated as important and the Lasso technique can be used for model selection.

*c) Elastic Net*

This method incorporates both penalties from Lasso and ridge regression regularization technique.

$$\lambda(\alpha\sum_{j=1}^{p}|\omega_j| + \frac{1-\alpha}{2}\sum_{j=1}^{m}\omega_j^2) \qquad \text{Equation 3.3}$$

where $\boldsymbol{\alpha}$ = 0 corresponds to ridge and $\boldsymbol{\alpha}$ = 1

Thus, if $\boldsymbol{\alpha}$ = 0 corresponds to a ridge and $\boldsymbol{\alpha}$ = 1 a Lasso. Choosing an $\boldsymbol{\alpha}$ value between zero and 1 optimizes the model to an elastic net, which shrinks some coefficients and sets some to zero for sparse model selection. The elastic net model was chosen for this analysis.

The Elastic net model was run using all the variables selected in the table above. The analysis was done using the package glmnet in R. In the first step, the optimal value of $\lambda$ is selected using a K fold cross-validation process. In this process, the data is separated into training & validation sets. A range of lambda values was then proposed in this case from -3 to 5 and for every fixed lambda, first, the training data was used to get a coefficient vector. The algorithm then implements this constructed model to predict on the validation set to get the error. The lambda that gives the smallest error term is selected as the most optimal. The minimum $\lambda$ was used in the subsequent model selection. Final selected variables were those with coefficients provided.

The remaining variables in addition to physician workforce and poverty were used in fitting the multivariable model. Significance was defined as having $p<0.05$ and was only interpreted for the accessibility variable. The assumptions of ordinary least squares regressions were tested using residual plots and normal QQ plots. A linear regression is appropriate if the points in the residual plot are randomly dispersed around the horizontal axis; else, a non-linear model would be more appropriate. QQplots were also produced as an additional normality check [Zuur et al., 2010]. Finally, Cook's distance, was used to identify influential outliers in the predictor variables. Cooks distance is commonly used to identify points that negatively affect the regression model. It represents a combination of each variable's leverage and residual; thus, the higher the leverage and residual values, the higher the Cook's distance. The influential data points can be checked by removing them and then checking again the model fit. The analyses were done in R v3.5.1.

## 3.3 Results

### 3.3.1 Data exploration

MMR ranged from 51.6 in Cape Verde to 1074.3 per 100,000 livebirths in Central Africa Republic. The mean MMR in 2015 was 401.0, with a median of 372.0 and an interquartile range of 196.9 deaths per 100,000 livebirths. The mean NMR for the countries was 26.34, ranging from 14.17 and 14.76 in Botswana and Cape Verde respectively to 40.16 and 40.60 in the Central African Republic and Mali respectively. Thus, similar to MMR, there were observed high values of NMR in the Central African Republic and low values in Cape Verde. Correlation between NMR and MMR for 2015 was 0.61. The violin plot in Figure 3.1 shows the distribution of the outcomes. Variation in access by country was shown in Table 2.4 but Figure 3.2 shows the dot distribution of the confounders in addition to the dot distribution of geographic access to hospitals.

Figure 3.1 Violin plots showing the distribution of MMR and NMR. The white dot is the median; the thick black bars represents the interquartile range; while the thin black line is the 95% confidence intervals. The grey region is the kernel density estimation region showing the distributions and shape of the data. Wide kernel density regions show that the probability of finding members is higher while the narrower regions represent a lower probability.

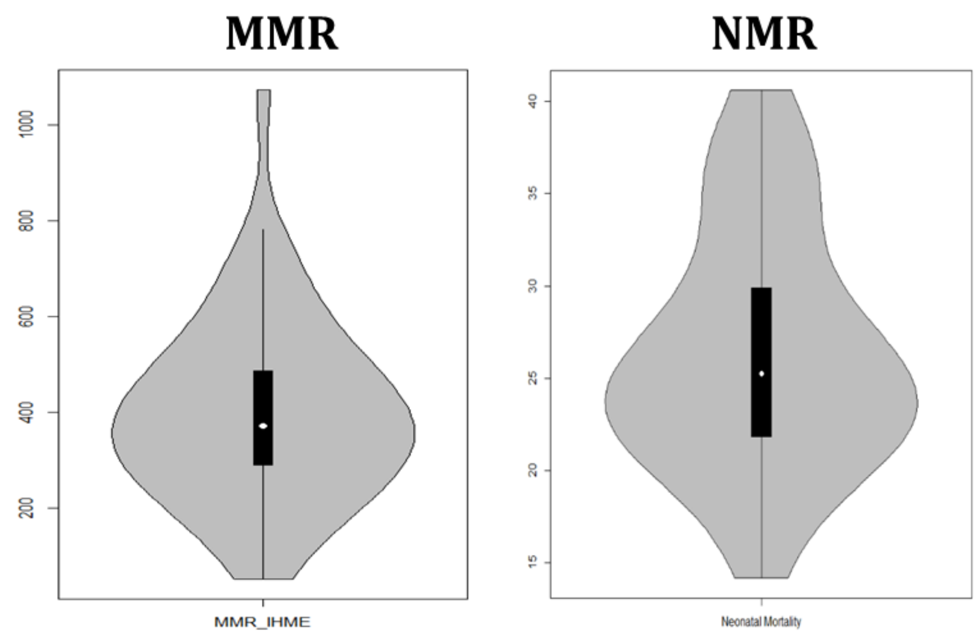
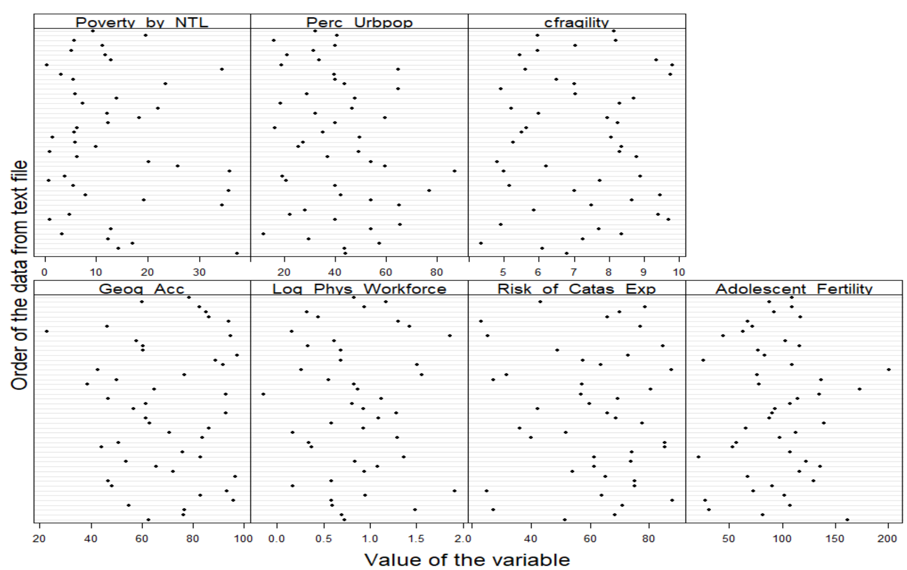



Figure 3.2 Dotplot of the variables showing distribution of data.




**Footnote:** Perc_Urbpop; Percentage of urban population, cfragility; measure of political instability, Geog_Acc; percentage of WoCBA within 2 hours of a hospital. Log_Phys_Workforce; Log adjusted physician workforce; Risk_of_Catas_Exp; Percent population at risk of catastrophic expenditure to surgery, Adolescent_Fertility Adolescent Fertility (Number per 1,000 livebirths)

The descriptive statistics showing the range, mean, median and the interquartile ranges of the covariates used in this relationship assessment are shown in Table 3.1. There were significant variations across the countries for all the variables.

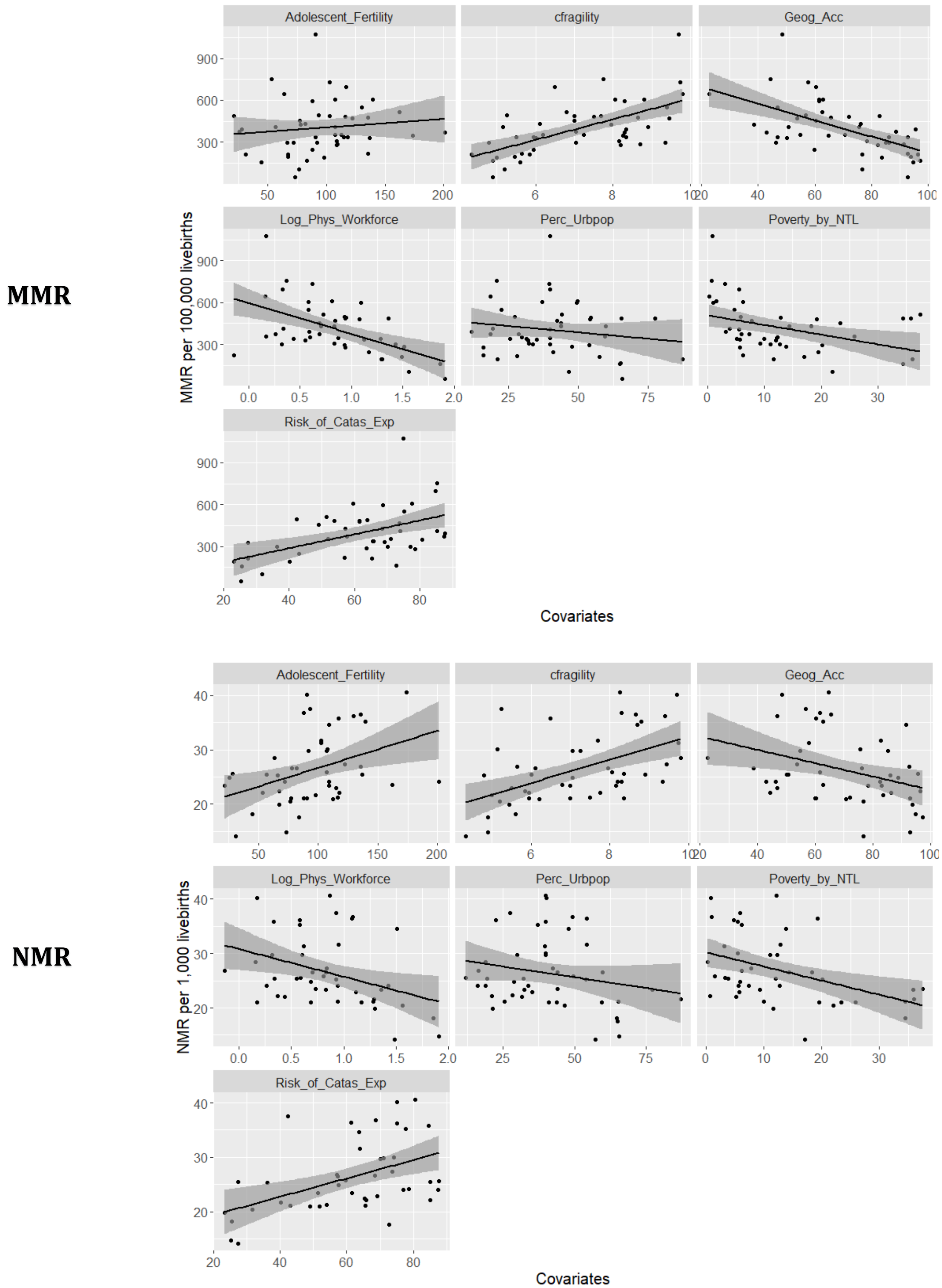
Table 3.1 Descriptive statistics of the confounders. The table highlights their respective means, median values, range and interquartile ranges (IQR).

| **Covariates** | **Mean [Range]** | **Median [IQR]** |
|---|---|---|
| Geographic Access (%) | 69.7 [22.7 - 97.3] | 70.7 [55.7 - 85.6] |
| Log transformed physician workforce | 0.8 [-0.1 - 1.9] | 0.8 [0.5 - 1.1] |
| Poverty (%) | 12.7 [0.3 - 37.4] | 10.5 [5.5 - 18.5] |
| Risk of catastrophic expenditure (%) | 60.6 [23.2 - 87.7] | 64.6 [50.80 - 74.3] |
| Proportion of urban population (%) | 40.8 [12.0 - 87.1] | 39.9 [28.5 - 51.8] |
| Fragility and political instability (composite index from 1-10) | 7.1 [4.35 - 9.8] | 7.0 [5.75 - 8.3] |
| Adolescent Fertility (Number per 1,000 livebirths) | 95.1 [21.2 - 201.2] | 93.2 [72.61 - 115.5] |

### 3.3.2 Assessment of Bivariable relationships

The crude (bivariate) analysis shows that accessibility was significantly associated with both MMR and NMR. Increasing proportion of population with access to public hospitals was associated with reduction in MMR with a coefficient of -5.90 [95% CI -8.37 to -3.42). Similarly, proximity to public hospitals access was associated with reduction in NMR with a coefficient of -0.12 [95% CI -0.22- to -0.03]. Relationship of all other unadjusted including that of access with both MMR and NMR are visualised in Figure 3.3 and Table 3.2.

Figure 3.3 Bivariable relationship between all predictors and both outcomes.




**Footnote:** Perc_Urbpop; Percentage of urban population, cfragility; measure of political instability, Geog_Acc; percentage of WoCBA within 2 hours of a hospital. Log_Phys_Workforce; Log adjusted physician workforce; Risk_of_Catas_Exp; Percent population at risk of catastrophic expenditure to surgery, Adolescent_Fertility Adolescent Fertility (Number per 1,000 livebirths)

Table 3.2 Estimated coefficients for the bivariable relationships between covariates and both MMR and NMR. The primary variable was geographic access to hospital care.

| | MMR | | NMR | |
|---|---|---|---|---|
| **Covariate** | **Estimate [95% CI]** | **p values** | **Estimate [95% CI]** | **p values** |
| **Geographic access to hospitals** | **-5.90 [-8.37 - -3.42]** | **<0.000** | **-0.12 [-0.22- -0.03]** | **0.014** |
| Log transformed physician workforce | -6.16 [-9.12 - -3.19] | <0.000 | -5.07 [-9.09 - -1.04] | 0.015 |
| Poverty | -6.93 [-11.92 - -1.94] | 0.008 | -0.26 [-0.43 - -0.09] | 0.003 |
| Risk of catastrophic expenditure | 4.98 [2.28 - 7.68] | 0.001 | 0.16 [0.07 – 0.27] | 0.001 |
| Percentage of urban population | -1.83 [-5.13 - 1.48] | 0.200 | -0.08 [-0.19 – 0.03] | 0.160 |
| Fragility | 9.84 [6.40 - 13.27] | <0.000 | 2.15 [1.10 – 3.19] | <0.000 |
| Adolescent fertility | 0.60 [-0.91 - 2.12] | 0.426 | 0.07 [0.02 – 0.12] | 0.006 |

### 3.3.3 Multivariable models

Only variables with $p<0.20$ were included in the subsequent analysis. The elastic net regression was fitted with two variables in the MMR analysis; Risk of catastrophic expenditure and Fragility. Poverty and physician workforce were included in the subsequent multivariable model by default and thus excluded from the ridge regression. Using NMR as the outcome, adolescent fertility, percentage of urban population, risk of catastrophic expenditure and fragility were used. Only adolescent fertility was significant in the bivariable relationship with NMR but not was not significant in the bivariable relationship with MMR. Selection outputs as given by the coefficients are shown in Table 3.3.

Table 3.3 Variable selection results from the elastic net regression. The variables with coefficients were the ones chosen while those with dots were the one dropped. Variables in grey were excluded in the ridge regression.

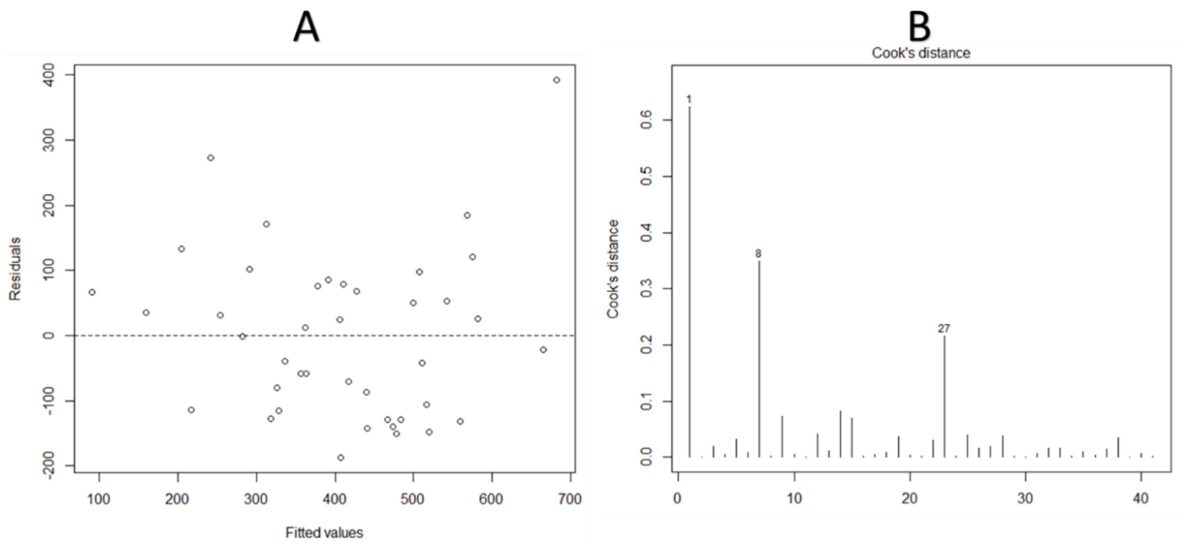
| **Variable** | **Coefficient (MMR)** | **Coefficient (NMR)** |
|---|---|---|
| Intercept | -2.421 | |
| Risk of catastrophic expenditure | 0.009 | 0.009 |
| Percentage of urban population | | . |
| Fragility | 0.253 | 0.236 |
| Adolescent fertility | | . |

The multivariable (adjusted) models therefore had five variables, geographic access to hospitals, poverty, physician workforce density, risk of catastrophic expenditure and fragility as the predictors. Using MMR as the outcome, increasing the proportion of women of childbearing age living within 2 hours of a hospital by one percent was associated with a decline in MMR by approximately 2.754 per 100,000 livebirths (p=0.037). Thus, assuming 35,000,000 livebirths occurred in 2015, ensuring hospital services are geographically accessible translates to 1,000 maternal deaths averted. However, the proportion of population within 2 hours of a hospital was not significantly associated with NMR. The adjusted model coefficients of accessibility are shown in Table 3.4. When the adjusted model was run using the 1-hour travel time also generated in Chapter 2, the coefficient was -0.019 (p=0.702). The residual plot for linearity and cooks distance test did not reveal any concerns for the linear model as shown in Figure 3.4. Because access was not significantly associated with NMR similar plots were not produced.

Table 3.4 Coefficients of the final model showing their confidence intervals and the p value

| **Variable** | **MMR** | | **NMR** | |
|---|---|---|---|---|
| | **Coefficient [95% CI]** | **p value** | **Coefficient** | **p value** |
| Intercept | 384.495 [24.747 to 744.244] | 0.037 | 20.311 [5.735 to 34.889] | 0.007 |
| Geographic access to hospitals | -2.754 [-5.357 to -0.151] | 0.039 | -0.019 [-0.125 to 0.086] | 0.717 |
| Log transformed physician workforce | -118.738 [-231.574 to -5.901] | 0.027 | -1.579 [-6.151 to 2.993] | 0.489 |
| Poverty | -0.505 [-5.489 to 4.478] | 0.839 | -0.140 [-0.3412 to 0.062] | 0.170 |
| Risk of catastrophic expenditure | 0.188 [-3.268 to 3.643] | 0.040 | 0.016 [-0.124 to 0.156] | 0.822 |
| Fragility | 42.674 [5.187 to 80.161] | 0.913 | 1.342 [-0.176 to 2.862] | 0.082 |

Figure 3.4 A) Residual plot for the final model showing distribution of residuals around the value zero. The random distribution between negative and positive shows that the variance around the regression line is the same for all values of the variables. B) Influence plot for the final model showing the data point on the x axis against the calculated cooks distance. The longer the cooks distance the more influential the data point. In this case, data point 1 was the most influential with a value of 0.63.




## 3.4 Discussion

Proximity to hospitals was only significantly associated with reduction in MMR after controlling for confounding variables. Geographic access to hospital care was the primary variable and the influence of other confounders were not analysed. Thus, a percent point increase in population living within 2 hours resulted in decreased MMR by 2.73 per 100,000 livebirths (p=0.038), in a model that adjusted for physician workforce and fragility. This means that with an estimated 35,000,000 livebirths occurring in the region in 2015, approximately 1,000 maternal deaths could have been averted by increasing the proportion meeting the threshold of access to emergency hospital services [WHO et al., 2009]. Countries with poor access and outcomes such as South Sudan, Eritrea and Central African Republic can reduce MMR to approximately 490, 95 and 84 deaths per 100,000 livebirths by ensuring that 80% of their women of child bearing age live within 2 hours of a hospital providing CEmONC services.

Studies in SSA have shown that longer travel times to emergency hospitals increase the risk of maternal death [Hoj et al., 2002; Pirkle et al., 2011; Hanson et al., 2015]. In rural Tanzania, a community survey found that maternal mortality was nearly four times higher in women living 35 Km to the nearest hospital compared to those living within 5 km [Hanson et al., 2015]. A hospital based study in Mali reported that travel times of more than 4 hours were associated with much higher maternal deaths [Pirkle et al., 2011]. None of the studies investigated the influence of the recommended 2-hour threshold, which forms a basis for measuring geographic marginalisation from comprehensive emergency obstetric care.

In contrast to the MMR analysis, there was no evidence of an association between geographic access to hospital services and neonatal mortality, whereby despite the final model showing an inverse relationship between access and NMR, this was not statistically significant. This lack of an association is not unique, and has been reported in Zambia and Malawi [Lohela et al., 2012], and may be due to several factors. First, given the poor coverage of vital registration systems, countries rely on household survey data for auditing neonatal deaths. In such surveys, under-reporting of neonatal deaths is always a challenge where interviewees may choose not to report them or those which occur immediately after birth are often recorded as still births [Neal, 2012]. Secondly, the chain of events leading from geographic access to outcome may be interrupted by several factors such as inability to pay for services, waiting times or quality of care received and this may affect the observed relationship. The sensitivity analysis conducted using the 1-hour travel time did not reveal any significant difference from the 2-hour model. Lastly, the proportion of population living within a two-hour travel time of a hospital was used but this may present as a challenge given that the time to death for different causes of neonatal death may vary. Thus, this study identifies the need for improved data collection on outcomes and determinants at individual level for better assessment of relationships.

In addition to improving access, countries should also focus on improving coverage of other determinants of mortality. Even though practices such as ANC use and skilled birth attendance were not used in the model presented here, to avoid circularity with the way MMR and NMR were computed (Section 1.6), they are key interventions towards reducing both maternal and newborn deaths. Other confounders that were used include physician workforce density which is important in ensuring services are available and political stability that creates an enabling environment for availability of both maternal and newborn health services. Although data on workforce such as nurses and clinical officers was not available for inclusion in the model they are also important in reduction of both maternal and neonatal deaths. Ultimately, achieving SDG goals for both NMR and MMR will require multisectoral approaches that account for multiple factors.

### 3.4.1 Limitations

This was a multivariable analysis that used national level data to examine the relationship between access to hospitals and both MMR and NMR. In the absence of accurate vital registration systems in SSA, the alternative would be to use household surveys such as the DHS which monitor MMR but these are only conducted at different time points for each of the countries. The indicator of access used in this chapter, despite being improved on what others have previously used still had several limitations, most of which were discussed in Chapter 2. Notably is the assumption that all the hospitals perform services required for provision of emergency obstetric care. Service availability and quality of care at hospitals is, however, a concern and modelled estimates suggest that mortality due to poor quality in Africa may be more than those due to lack of services at all [Kruk et al., 2018]. A study done in Kenya, Malawi, Nigeria and Sierra Leone found that only a quarter of the hospitals surveyed provided all the nine signal functions required to provide emergency obstetric care [Ameh et al., 2012]. Similar results have been obtained in Burkina Faso, where only 27% of the hospitals in the country were able to provide the two signal functions for provision of comprehensive emergency obstetrics [Compaoré et al., 2014]. These show that the accessibility to hospital metrics used may overestimate access to emergency obstetric care ultimately affecting the relationship observed.

Not all the covariate data was available for 2015 and some were collected in different time periods and this may affect comparability in different countries. To limit the influence of this challenge, data extraction was limited to only those taken after 2010. Effort should be directed towards improving health metrics data in order to provide more accurate relationships. Finally, some potentially important covariates that might drive MMR like surgical workforce, number of obstetricians and the number of hospital births were not comprehensively captured across the countries and these could affect the results obtained.

### 3.4.2 Summary

In summary, this chapter shows that, notwithstanding the data limitations, geographic access is significantly associated with maternal mortality. The other factors that increase the risk of MMR were found to be fragility and physician workforce. Countries should therefore aim at reducing geographic accessibility gaps if the SDG on maternal mortality is to be achieved. However, the main limitations of this analysis in exploring the relationship are; the assumption that hospitals provide crucial CEmOC services with good quality, this may over estimate access and thus making it difficult to explore how it relates with the outcomes. Secondly, the use of national level determinants may mask finer heterogeneity at subnational level, further affecting the observed relationship. Chapters 4 and 5 seek to address some of these limitations. In Chapter 4, two tracer conditions – ability to provide caesarean deliveries and care for very low birth weight children - will be used to select hospitals able to provide key CEmONC services that should be available at hospitals in Kenya.

# Chapter 4: Geographic Access to Kenyan Hospitals Offering Emergency Care Using Two Tracer Indicators.

## 4.1 Introduction

In Chapter 2, a database of public hospitals covering 48 SSA countries was assembled with the assumption that they all provide CEmONC (Section 1.5.7). In the absence of accurate data on service availability, a review of health sector strategic plans (HSSPs) in each country (Section 1.6.7), showed that district hospitals are the first points of contact with the health systems, where CEmONC can be obtained. The hospital inventory was subsequently used to define geographic accessibility to public hospitals for women of childbearing age, to highlight access gaps for CEmONC services (Chapter 2) and the impact on MMR and NMR (Chapter 3).

This process was, however, subject to some significant limitations that would affect the outcomes and the associations in Chapter 3. First, the definition of what a hospital is in SSA remains unclear, given that any facility with the word hospital attached to its name was assumed to offer at a minimum first level referral services, with the definition not linked to data on service availability. Several studies have reported the inadequacy of hospitals in SSA to provide these basic inpatient services [Hunger et al., 2007; Compaoré et al., 2014; Echoka et al., 2014; Rajbhandari et al., 2020].

Secondly, population maps used in Chapter 2 were developed using models that included covariates such as proximity to roads and health facilities, and these may also overestimate accessibility due to introduced circularity. It was not possible to correct for this limitation as most countries lack high-resolution population data, thus the heavy reliance on covariates for population disaggregation. Lastly, the access model in Chapter 2 did not account for barriers to physical access like seasonality, in addition to not exploring the full spectrum of neighborhood structure required for accurate spatial analysis. Focusing on one country, Kenya, provides an opportunity for improving the definition of what a hospital is, based on an assessment of service availability, and refine the accessibility model.

This chapter had three main objectives. First was to assemble a comprehensive list of facilities that are likely to provide inpatient neonatal and obstetric care using various sources of information on service availability and. This was done using caesarean sections (CS) and very low birth weight services (VLBW) services as tracer conditions. These were chosen as they are critical clinical services that can significantly reduce maternal and neonatal mortality. The detailed justification for using these tracer conditions is provided in detail in Section 4.3. The second objective was to map the propotion of livebirths in need of these services. Here, enumeration area (EA) data (synonymous with village level) on population distribution was used to disaggregate population distribution in Kenya. This was done using a parsimonious model that excludes covariates that introduce circularity when modelling proximity to health services. Crude birth rate data and literature review data on births likely to require both services was then used to derive the proportion of births requiring CS and VLBW services. Subsequently, a model that adjusts for land use, elevation, road condition and seasonality was built to define geographic access to these hospitals. The Chapter concludes with a discussion on implications of the results, recommendations and limitations.

## 4.2 Country Context

### 4.2.1 Geography

Kenya is an East African country bordered to the West by Uganda, to the North West by South Sudan, to the North by Ethiopia, to the East by Somalia and to the South by Tanzania. To the south-east, the country has a 536-km coastline along the Indian ocean. Kenya's area is approximately 580,367 km$^2$ and lies between latitudes 5$^0$00'N and 4$^0$40'S and between longitudes 33$^0$83'E and 41$^0$76'E. Climate varies by location with long term average precipitation highest in areas around the lake basin, the central rift valley regions and central Kenya regions. Temperature also varies with lower average values in areas at altitudes of more than 1,000 m above mean sea level and higher temperatures in areas of lower altitudes such as the coastal region or the arid and semi-arid areas in the Northern parts of the country. Administratively, the country is divided into 47 semiautonomous units called counties (Figure 4.1). The counties are further divided into sub-counties which in most cases correspond to constituency boundaries. Sub-Counties are further divided into county assembly wards for administrative purposes.

Figure 4.1 Kenya's 47 counties.


### 4.2.2 Kenya's Health System

The new constitutional dispensation established in 2010 was a major milestone towards accelerating the country's progress in improving health standards [GoK, 2010]. Article 43 identifies access to healthcare, including reproductive health and emergency care, as a fundamental right for all Kenyans. Article 53 provides that every child has a right to basic healthcare while article 56 articulates the need for the state to expand access to healthcare to marginalized communities [Kimathi, 2017]. Ensuring equity in access to healthcare requires a functioning health system, in an environment that leaves no one behind. Historically, some regions of the country have persistently had poor health outcomes, in part due to inequities in access to health services brought about by the centralized form of governance. The expectation was that the adopted devolved system would aid in bridging these gaps [GoK, 2010].

The new devolved system of governance was fully adopted in 2013 and responsibility for the provision of healthcare was divided between the county and national governments. The national government retained the functions for developing health policies, governing national referral hospitals and providing technical assistance to the counties. The 47 counties, on the other hand, were assigned the roles of management of primary health services including first level referral hospitals and secondary hospitals which provide essential services at the community levels [MoH, 2017]. Access to these services is anchored on four pillars of the health system [MoH, 2014a]: 1) availability of an adequate network of health facilities; 2) Adequate staffing at the facilities; 3) adequate supply of essential medicines and equipment at the recommended levels and 4) financing for the various health programmes should be adequate. These are discussed in detail below.

### 4.2.3 Health Service Delivery

Health service delivery in Kenya is organised in six levels, from the community health facilities in level 1 to national referral facilities in level 6 [MoH, 2014a]. However, the Kenya health policy framework identifies that the health service delivery system will transform from the current six tiers to a four-tier system by 2030, to ensure better service delivery as the country continues to devolve most of the services to the county level. Ideally, services are offered with increasing sophistication from the community level to national referral hospitals. The current levels of service provision including the desired changes by 2030 are shown in Table 4.1. The focus of this study is on the hospital levels of care as defined at the onset of devolution.

Table 4.1 Levels of care in the Kenyan health system from when the policy was adopted, during the implementation phase and the desired level at the end of the policy period.

| **Corresponding levels of care at the beginning of the policy** | **Desired levels of care by the end of the policy** |
|---|---|
| Level 1: Community | Level 1: Community |
| Level 2: Dispensaries and clinics | Level 2: Primary care facilities |
| Level 3: Health centres | |
| Level 4: Primary care hospitals | Level 3: County hospitals |
| Level 5: Secondary care hospitals | |
| Level 6: Tertiary care hospitals | Level 4: National referral hospitals |

**Footnote:** The cells shaded in orange show the levels managed at the county level. Currently, the six-tier system of disaggregation is in use and is adopted henceforth.

The categories are normally assigned when facilities are constructed based on the range of services they are expected to provide. For government facilities, this is done during gazettement while for non-government facilities the inspection should be done prior to licensing [*Personnal communication with MoH - Health Information System unit*]. This can be a challenge especially when the process lacks coordination and a streamlined process of verification when facilities are in operation. In January 2019, the master health facility list reported 10,909 health facilities providing a range of services from general outpatients to specialized services [MoH-HIS, 2016]. These are managed by the MoH (48%), private sector (40%) and faith-based organizations/non-governmental organizations (11%). Other government-run facilities that provide services for target groups like armed forces or company medical services make up less than 1% of health care providers [MoH-HIS, 2016].

It is recommended that counties should have at least one dispensary per 10,000 population and 30,000 per health centre. Primary hospitals should serve at least 100,000 people while secondary hospitals have coverage of 1,000,000 people [MoH, 2017]. Counties with high access quotients include Baringo, Elegeyo-Marakwet and Lamu with less than 3500 persons per public facility may mask the longer travel distances patients may travel to receive care. Distance affects the ability to obtain adequate services, and this may be one explanation for why some counties have high facility to population ratios but poor health outcomes. This Chapter focuses on access to maternal and newborn services and the subsequent health system discussions on service availability, health workforce and health financing focus on these two areas.

Maternal and newborn services have been integrated into all the levels of service provision: Level 1 and 2 provide routine services like normal deliveries, family planning services, antenatal care and identify danger signs requiring immediate referral. Level 3 facilities provide BEmONC in addition to level 1 and 2 services. CEmONC services are provided at Level 4,5 and 6 hospitals [MoH, 2011]. All the services are summarized in Table 4.2. To achieve maximum benefit, a referral system is proposed, that aims to ensure the movement of patients to and from the different levels based on the need. A 2013 appraisal of the referral system in Kenya found inadequacies, with challenges such as inadequate transport to expedite emergency referrals and lack of unified guidelines on referral processes [USAID & MEASURE Evaluation PIMA, 2013].

As a result, the MoH in 2014 developed a referral strategy that aimed at improving the efficiency and effectiveness of the referral system [MoH, 2014b]. Proposed solutions included improving communication between facilities, ensuring availability of ambulances and improving the capacity of health providers in identifying need for referral. Efficiency and effectiveness was also to be achieved through equipping facilities with referral guidelines, reducing referral times (waiting time, transport time and decision-making time), encouraging counties to map referral zones for efficient allocation of resources and setting up of a national referral coordination unit [MoH, 2014b].

Table 4.2 Levels of maternal and newborn care (columns) in Kenya categorized by the different levels of service provision. This cuts across the continuum of maternal and newborn service provision. The orange column shows hospital level services [MoH, 2011]. The rows show the different categories of services.

| **Level 1** | **Level 2** | **Level 3** | **Level 4,5,6 hospitals** |
|---|---|---|---|
| Promotion of healthy behaviours such as antenatal care attendance, skilled birth attendance, hygiene | All level 1 services plus; | All level 2 plus; | CD4 count Rhesus incompatibility Ultrasound |
| Early recognition of danger signs for mother and baby and initiate referral | Normal delivery | BEmONC services; Parenteral oxytocics to augment labour or management of postpartum haemorrhage, Parenteral antibiotics to treat puerperal and newborn infections, Parenteral anticonvulsants to manage (pre) eclampsia, Manual removal of placenta, Manual Vacuum Aspiration for incomplete abortion, vacuum extraction) Newborn resuscitation | Comprehensive Essential Obstetric Care (CEOC) 6 BEOC signal functions plus Blood transfusion Surgical procedures (C-section, Laparotomy for Ectopic pregnancy or ruptured uterus, destructive vaginal operation, dilation and curettage). Ultrasound for diagnosis and monitoring. |
| Promotion and monitoring of newborn care | Essential newborn care: Keeping baby warm, KMC, identification of danger signs, | Essential newborn care through oxygen therapy | Essential Newborn Care (ENC) Management of severely ill newborns Management of low birth weights/prematurity Management of congenital anomalies Phototherapy and exchange transfusion |
| Establishment of maternal and newborn death reviews | Targeted postpartum care | | |
| Family planning promotions and outreach programs | Family planning; Lactation Amenorrhea Method Injectables Hormonal Pills Condoms (male and female) Natural methods Emergency Contraception (EC) | Family Planning Implants | Family Planning Sterilization (Bilateral Tubal Ligation and vasectomy) |

### 4.2.4 Health Workforce

The devolved system of governance created an enabling environment for counties to increase human resource capacity. The health workforce capacity in Kenya varies within and between counties. In 2018, the density of medical officers was 0.6 per 10,000 population, against the KePH requirement of 3.7 per 10,000 population [MoH, 2019]. Similar, deficiencies were reported for clinical officers where the ratio was 3 per 10,000 population, lower than the intended 3.7 per 10,000 population. The density of core health workers (medical officers, specialist medical doctors, non-physician clinicians, nursing professionals, and midwifery professionals) was 15.6 per 10,000 falling below the WHO recommended figure of 23 per 10,000 population. In 2018, only six counties - Lamu (24.6), Kajiado (24.6), Nairobi (26.3), Uasin Gishu (28.2), Nyeri (31) and Tharaka Nithi (33.8)- surpassed the WHO target. Sixteen counties had a density of less than 10 core health workers per 10,000 population [MoH, 2019].

Gaps in medical specialists have also been reported, for example, a recent survey of medical staff in facilities found gaps in almost all cadres with the average number of specialists such as radiologists, obstetricians and gynaecologists, surgeons, paediatricians and anesthesiologists ranging between 0.1 and 0.3 against the requirement of at least 2 per hospital [MoH, 2019; English et al., 2020]. Although secondary hospitals (Level 5 and 6) performed relatively better in terms of availability of specialists, these hospitals are too few (n=19) to adequately serve the needs of the whole country. Such hospitals are also mainly found in major urban areas, and patients in rural areas who need specialist medical care face significant challenges in accessing higher level services.

### 4.2.5 Health Financing

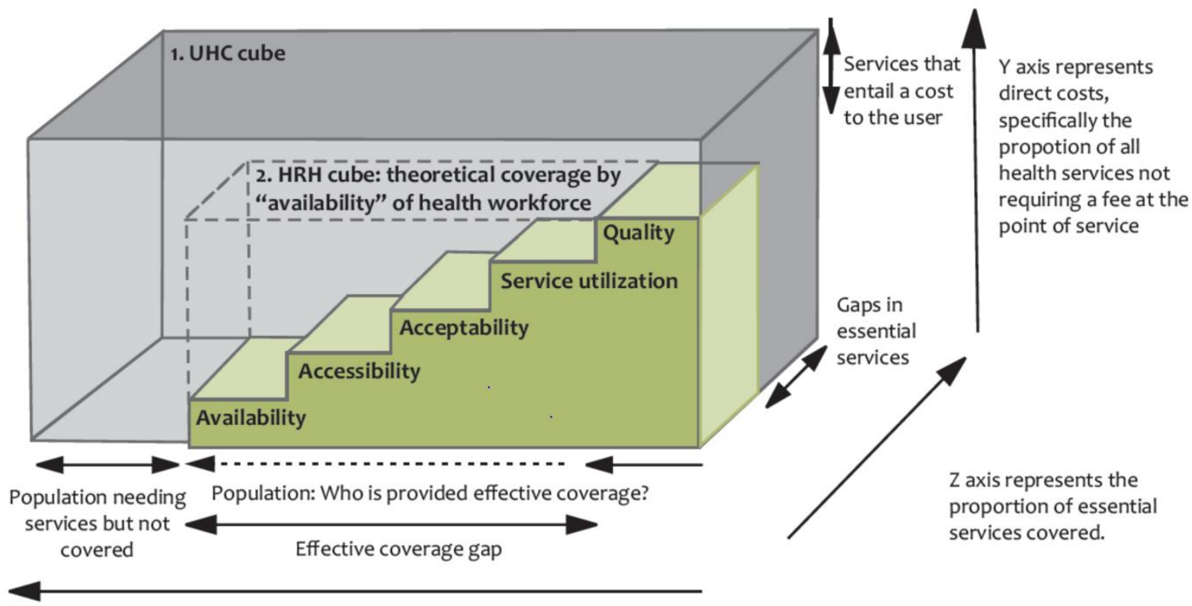
Over the past three decades, Kenya has undergone several reforms aimed at achieving financial protection against catastrophic and impoverishing expenditures. Notable policies include the implementation of user fees between 1965 and 1989, which was abolished for a “10/20 policy” [Obare et al., 2018], that was in operation between 2004 and 2007. The 10/20 policy provided services free of charge in health centres and dispensaries except for a registration fee of 10 shillings and 20 shillings (approximately 2020 USD 0.1 and 0.3 respectively) in the respective facilities . More recently, in 2013, the user fees were abolished and since 2018, the ‘*Linda Mama Boresha Jamii*’ initiative which sought to improve coverage of free maternal care through tax-funding has been in operation. The Linda Mama programme aims to ensure that women who are registered in the National Hospital Insurance Fund (NHIF) scheme can access the full range of maternal and newborn services ranging from the antenatal period, delivery (including CS), emergency referrals and postnatal care [MoH & NHIF, 2016].

Despite the existence of these interventions, inequities in utilization of facilities persist, primarily driven by factors such as wealth/income status and distance to facilities, with those who are poor and living far from facilities often not seeking care or incurring huge costs to access care [Kukla et al., 2017]. A recent assessment of the 2018 Kenya Household Expenditure and Utilization Survey found that about 1 million people were pushed into poverty due to out of pocket health expenditures, with transportation costs being a significant driver of high cost of healthcare related spending [Salari et al., 2019]. Majority of those facing the financial hardships were often in rural areas where distances are longer, showing a relationship between poor geographic accessibility and increased risk of financial hardships [Kukla et al., 2017], i.e. the poorest (except urban poor) live further away from facilities and incur the dual burden of high costs and relatively long travel time. This suggests that despite government efforts to remove/reduce medical costs for maternal services longer distances and travel times may still pose significant bottlenecks in ensuring the poor and marginalized are financially protected.

### 4.2.6 Drive towards universal health coverage

Just like in many LMICs, Kenya has committed to achieving UHC by 2022 with a rollout of the programme in September 2018 [Wangia & Kandie, 2019]. This will be driven by health reforms and policies geared towards ensuring financial protection, ensuring services are available at each required level of care, providing quality services in a timely manner, health workforce improvement and improving health governance. These were described in the preceding sections and how they interact in achieving UHC shown in Figure 4.2. Achieving UHC will also be critical in ensuring maternal and newborn goals are attained. The next section therefore reviews performance of maternal and newborn sector in the country, with indication of how these vary at county levels.

Figure 4.2 UHC cube that shows the three dimensions of coverage; population coverage, service coverage, and financial coverage or financial protection adopted from [Wangia & Kandie, 2019].




### 4.2.7 Maternal and Newborn Health Indicators in Kenya

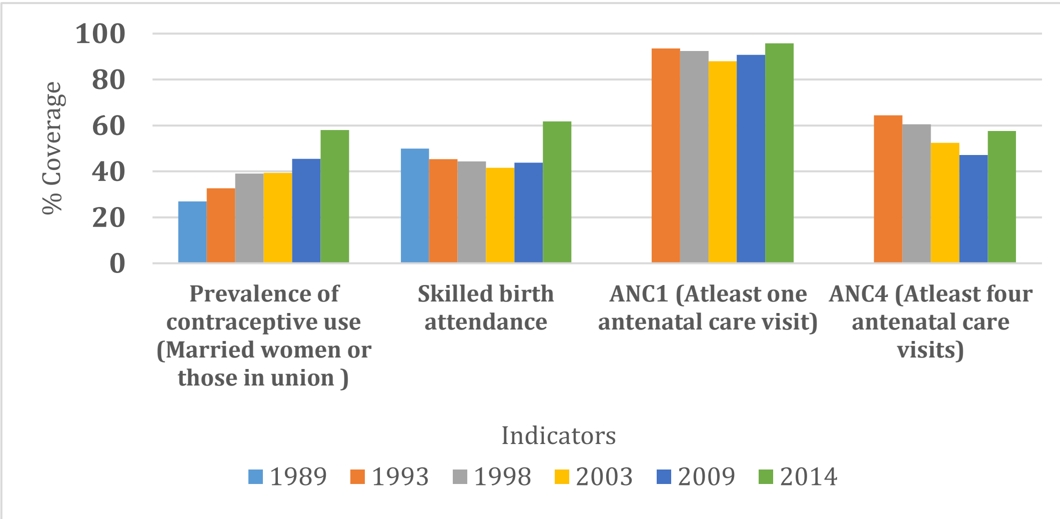
The Millennium Development Goals era saw Kenya make substantial gains in maternal and newborn health [Victora et al., 2016]. Despite the increase in maternal mortality in the 1990s, the country managed to reverse the trend, with a 39% reduction in MMR per 100,000 livebirths, from 590 in 1998 to 362 in 2014 [DHS Program, 2020]. Within the same period, NMR reduced by 25% from 28 to 22 per 1,000 livebirths. However, progress was insufficient to meet the MDG target of reducing MMR by three-quarters to 147, while the relative stagnation of NMR in the MDG period prevented the country from achieving the two-third reduction in under 5 deaths [Keats et al., 2017].

The mixed results were largely driven by poor coverage in key reproductive, maternal and neonatal health (RMNH) interventions and indicators [Keats et al., 2017]. Skilled birth attendance for example, increased from 50% in 1989 to only 62% in 2014, while the prevalence of contraceptive use increased from 27% in 1989 to 58% in 2014 [DHS Program, 2020]. Increases have also been observed for at least one antenatal care attendance, but dropout rates are still high to sustain the required coverage of at least four ANC visits as shown in Figure 4.3. These are only for national household survey datasets, the last of which was collected in 2014.

Fertility rates (births per woman) reduced consistently from 6.7 in 1989 to 3.9 in 2014. Adolescent fertility (% of women aged 15-19 already mothers) increased from 17 to a peak of 23 in 2003 but reduced to 18 in 2014 [DHS Program, 2020]. Temporal variation in the interventions and indicators might explain the differences observed in maternal and neonatal mortality. For example, the increase in maternal mortality in the 1990s occurred concomitantly with a reduction in skilled birth attendance, antenatal care attendance and the increased adolescent fertility rates within the same period [Keats et al., 2017]. The 1990s is also the period when the user fees were abolished as described in Section 4.2.5. As the country aims to reduce MMR to 113 by 2030 and NMR to 13 by 2030 [MoH, 2014c], there is need to attain UHC in interventions. Monitoring these interventions is only possible for the period when household surveys have been done and although these indicators can be obtained from the Kenya Health Information

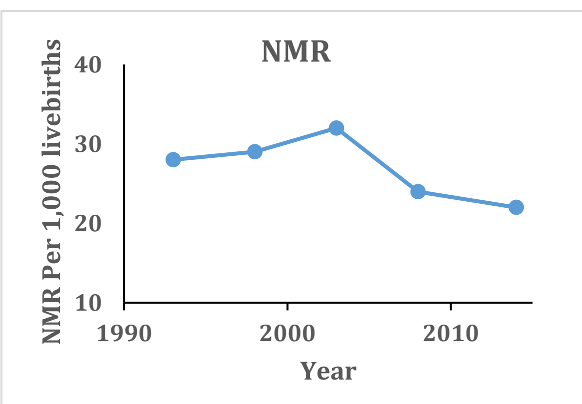
System, they cannot be presented here for comparison because they are not community level estimates.

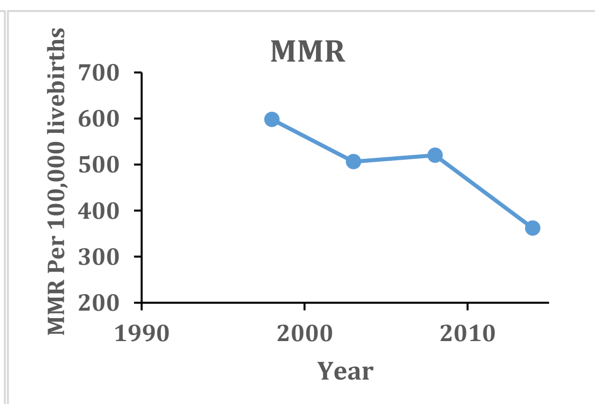
Figure 4.3 National level trends in intervention coverage of key RMNH indicators as per demographic and health surveys done in 1989, 1993, 1998, 2003, 2009 and 2014 [DHS Program, 2020]. ANC attendance data was not available for 1989 and coverage is only presented from 1993 onwards. The years of survey are represented in different colors as shown in the legend. There have been no household surveys after 2014.




Trends in the interventions have been the drivers of observed changes in both NMR and MMR over the same period as shown in Figure 4.4. However, county level metrics could not be produced for both interventions and outcomes for the same period.

Figure 4.4 National-level trends in NMR and MMR from DHS surveys since 1993 to 2014.



Adequate planning for UHC at the very least requires monitoring coverage of both outcomes and interventions at sub-national levels. The 2014 DHS was powered to provide some RMNH estimates at county levels and significant variations were observed [KNBS, 2016]. For example, skilled birth attendance varied from as low as 21% in Wajir to more than 90% in counties such as Kirinyaga and Kiambu. Percentage of ANC 4 visits were as low as 18% in West Pokot and as high as 73% in Nairobi County [KNBS, 2016]. Differences in intervention coverages at subnational levels has ostensibly translated to variation in outcomes such as maternal and neonatal mortality [Keats et al., 2017]. The next section will explore the trends in maternal and neonatal mortality in Kenya and focus also on sources of data for maternal and neonatal mortality including how they were assembled.

#### 4.2.8 Disparities in maternal and neonatal mortality in Kenya

Several resources have mapped MMR and NMR at county levels. This section will review these results and propose those that will be used in Chapter 5.

*Maternal mortality*

In 2009, the Kenya **population census** used the sisterhood method (Section 1.5.1) to obtain pregnancy related deaths in the previous 12 months. The exercise collected deaths between mid-2008 and mid-2009 and data was presented at county levels [NCPD et al., 2015]. To calculate MMR in each county, Maternal deaths were then divided by the livebirths within the same period to obtain the county-level estimates of MMR. This output therefore represented an enumeration of all maternal deaths in the country devoid of any adjustments from covariates.

**Equist/MMEIG**; Maternal mortality ratio for national level are available globally from Maternal mortality inter Agency group (MMEIG) [MMEIG, 2016]. Except in a few countries, there are normally no estimates of maternal mortality ratio for subnational populations. In lack of a validated alternative, it is assumed that MMR for each subnational group is equal to the national level. An alternative option (such as in Kenya) is to use the Lives Saved Tool (LiST) tool to estimate MMR attributable to coverage [UNICEF, 2018]. Subnational values of the interventions are then used to estimate MMR at county levels. In this process, several covariates are used to disaggregate national values of MMR to sub-national levels. These covariates are; Water and sanitation, ITN use, access to family planning, immunization coverage, skilled birth attendance and antenatal care attendance.

The third source uses methods developed by the IHME, a global project to model maternal mortality [Achoki et al., 2019]. In the Kenya exercise, data was obtained from census, hospital data, VRS, published literature and surveys. Covariates used in the model were ANC, fertility rate, education years, malnutrition, total fertility rate, obesity and socio demographic status. A significant proportion of the sources of mortality data were from facility level datasets, which only represents the proportions of maternal deaths occurring at facilities. This means that the maternal deaths reflect the portion with access to facilities.

The EQUIST and census outputs were also largely similar, with the MMR burden highest in northern Kenya than anywhere else in the country. The IHME output however showed high burden of maternal deaths in central parts of the country including the capital Nairobi reflecting the influence of facility level datasets in the outputs. This source will therefore not be used to assess relationship with access in Chapter 5. Such differences can be attributed to differences in timepoints they represent, methodology and input data. However, given the scarcity of subnational level data on MMR, there is need for investment in data collection tools that can aid in provision of timely data at sub national levels.

*Neonatal mortality*

**Equist/UNIGME:** Rates of neonatal mortality for each country are extracted from national level estimates of the UN Inter-agency Group for Child Mortality Estimation [UNIGME, 2018]. Subnational level rates of under-5 mortality, infant mortality and neonatal mortality for subnational groups were estimated by applying the relative subnational distribution of interventions coverages from the relevant household surveys to the national IGME estimate for the baseline. The process also used the LiST tool and the relevant interventions to estimate NMR at county levels.

**IHME 2017:** Obtained both wide area and point data for complete birth history and summary birth history estimates of neonatal deaths. Several covariates were used to explain variation in neonatal deaths. These were; malnutrition, malaria prevalence, population density, fertility rates, enhanced vegetation index, land surface temperature, urbanization, maternal educational attainment, access to cities and night-time lights. An ensemble of four regression models (Generalized additive model, Boosted Regression Trees, lasso regression and ridge regression) was used to select the best fitting covariates. Bayesian MBG models were then fitted to estimate neonatal mortality at 5 by 5 km using the input data and covariates.

The third source was obtained from [Paige et al., 2019] where a Bayesian spatial conditional autoregressive model was fit to the 2014 neonatal mortality rate data from the 2014 DHS. In the model, no covariates were used for the prediction. Variation of NMR from the three sources at county levels are shown in Figure 4.5. Comparison shows that all the three sources were very different, stemming for the variations in methodologies, covariates and input data used. The EQUIST model for example showed that NMR was highest in northern counties like Marsabit and Samburu, but these same counties had lowest indices in the IHME outputs. NMR from Paige *et al.* (2019) did not show much variation in the country, with only Siaya and Mandera distinctly different from the rest of the country. Chapter 5 will aim to model the relationship between access and neonatal mortality and IHME output which used access to cities as a covariate, will not be used in the process. The other two sources will be used for comparison.

Although there are different outputs for MMR and NMR in Kenya, description of geographic disparities in MMR and NMR was based on the EQUIST model outputs. Differences in MMR at county levels was visible, ranging from 160 in Kirinyaga to 754 per 100,000 livebirths in Mandera. Other counties that had relatively poor maternal outcomes were Samburu, Turkana and West Pokot all which had an MMR of more than 600 per 100,000 livebirths. Neonatal outcomes were also poorest in Marsabit, Turkana and West Pokot, with these counties having NMRs of more than 50. No county had achieved the 113 per 100,000 livebirths MMR national SDG target of 2030, while 39 counties still fell short of reaching the less than 13 NMR that the country aims to achieve by 2030. This shows the importance of accelerating investment in improving maternal and newborn care with a specific focus on high burden counties. Chapter 5 will explore the association between access CEmONC and both maternal and neonatal mortality with the intention of identifying significance of improving access on reduction of the outcome. The next section will also provide in detail the causes of maternal and neonatal mortality in Kenya and also provide a rationale for selecting tracer conditions that point to readiness of hospitals to provide CEmONC services.

Figure 4.5 Variation in MMR per 100,000 livebirths from the three different sources labeled using the source and the years they represent

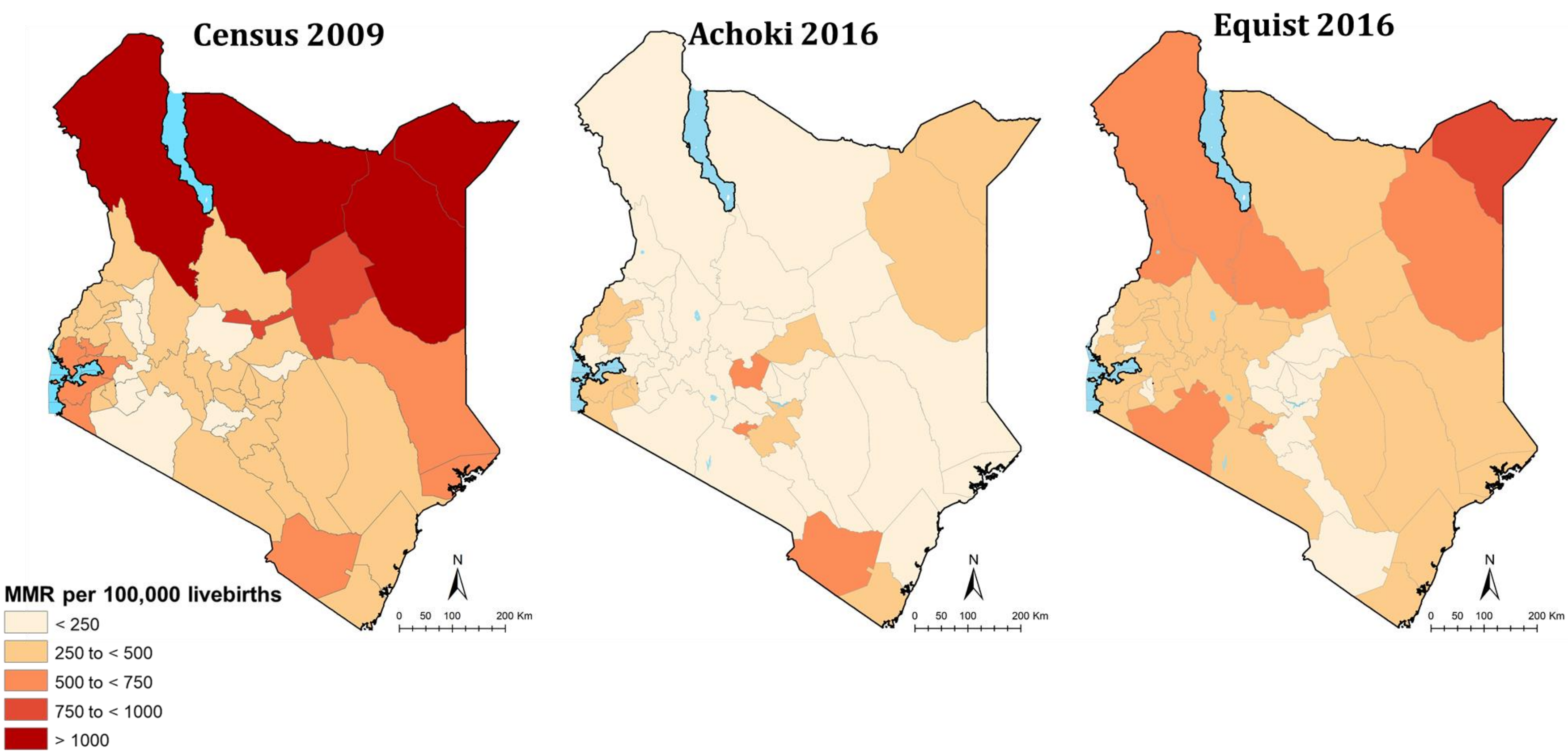
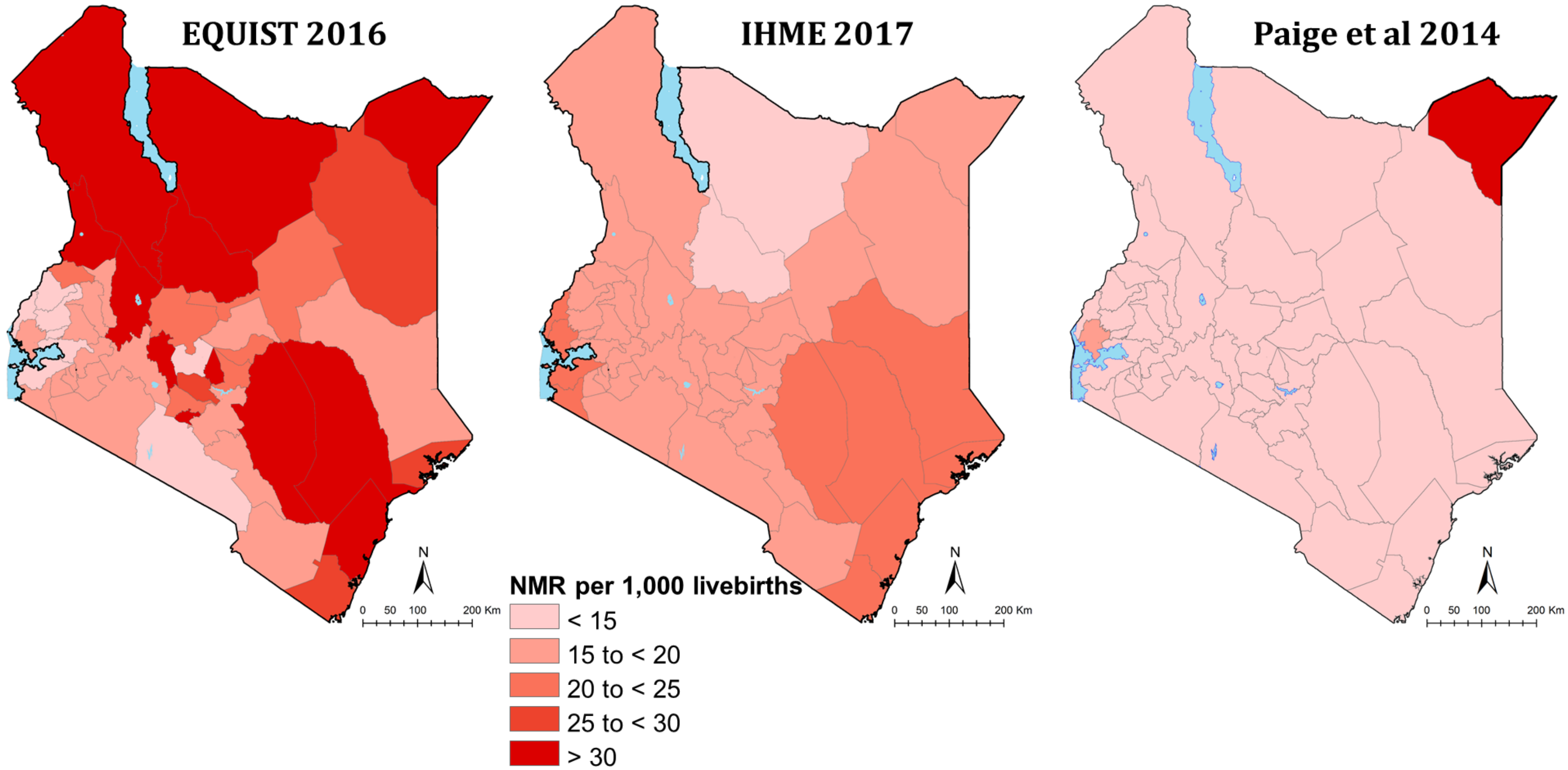


Figure 4.6 Variation in NMR from the three different sources labeled using the source and the years they represent



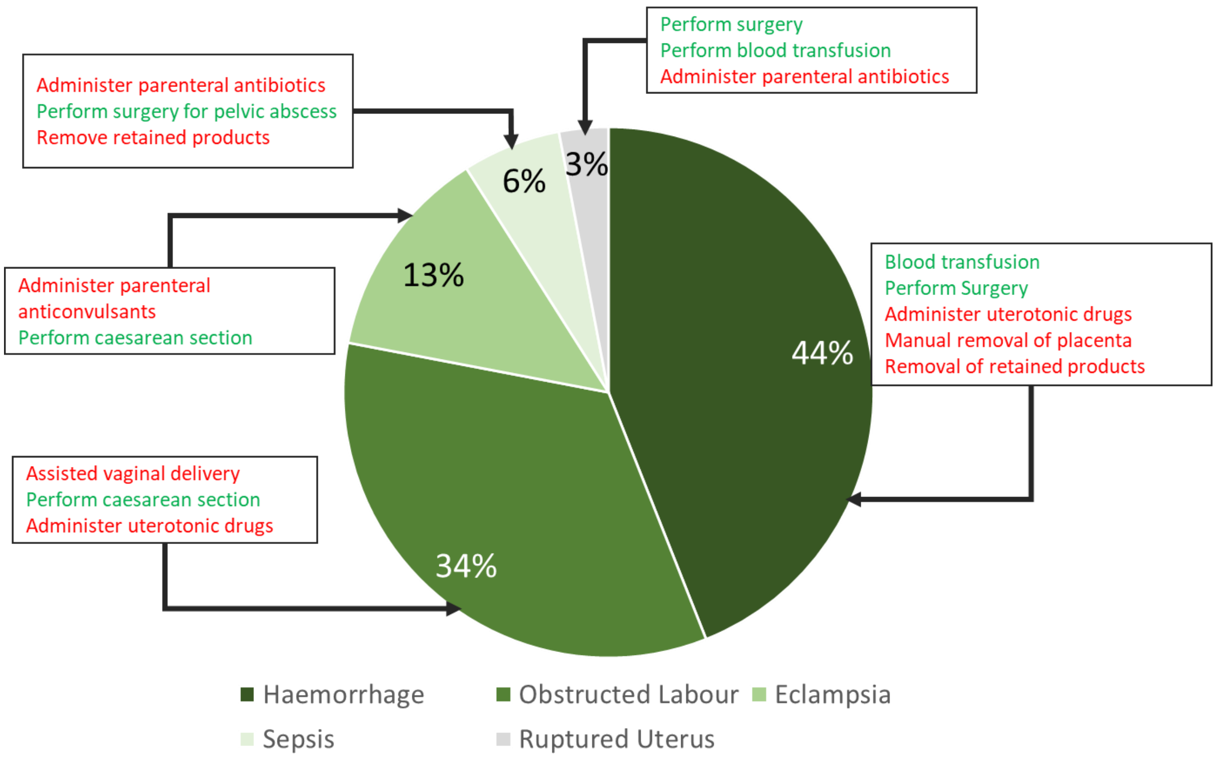
## 4.3 Rationale Behind Choice of Tracer Conditions

In Section 1.5.1, the cascade of maternal and newborn health services was reviewed. Maternal and newborn deaths, despite being priority areas for the health system in Kenya are still unacceptably high. Several hospital-based interventions are critical in the reduction of preventable maternal and neonatal deaths. As will be shown, maternal deaths in Kenya are due to causes such as haemorrhage, eclampsia (hypertension) and obstructed labour all of which require adequate caesarean section and blood transfusion to manage. Newborn deaths are also primarily driven by prematurity, congenital anomalies and respiratory distress. Thus, Caesarean sections and ability to provide very low birthweight (VLBW) services are also useful interventions required in routine hospital settings in Kenya and their availability will be used as an exemplar for determining hospital capacity to provide inpatient neonatal and maternal care. The next section will give a brief outline of why these interventions are important, particularly with regards to how they can avert a significant proportion of maternal and neonatal deaths.

### 4.3.1 Caesarean Section

Caesarean section is the most common surgical procedure and when required can save both the woman's and baby's lives when complications of delivery occur. Based on a systematic review of rates of causes of maternal and newborn mortality, the WHO set a benchmark of expected CS rates of 10% at community level for women delivering, because of its role in reduction of maternal and neonatal mortality [WHO, 2015b]. This is because most maternal deaths occur due to haemorrhage, eclampsia (hypertension) and obstructed labour most of which require CS and blood transfusion to manage [NCPD et al., 2015]. Indirectly, other factors that cause or aggravate maternal deaths include HIV/AIDS, anaemia, malaria and cardiovascular diseases [Say et al., 2014]. In Kenya, the most comprehensive assessment of causes of maternal deaths was an analysis of the 2009 census data. As shown in Figure 4.7, majority of the deaths can be managed by known interventions such as CS and blood transfusions, which are the two main components of CEmONC services [MoH, 2011].

Figure 4.7 A chart of the causes of maternal mortality in Kenya including the interventions (In boxes) needed to manage the causes. The green interventions are provided at the hospital level (level 4,5 and 6) while red interventions are provided at primary level services (level 2 and 3). The interventions at each level of care are described in detail in Section 1.6.1 [NCPD et al., 2015].




In addition to the known maternal conditions, CSs are performed when fetal conditions such as fetal distress, malpresentation/malposition, cord presentation, multiple pregnancies or in cases of fetal macrosomia (estimated birth weight >4000g) occur. The process for performing CS in Kenya requires access to an operating theatre, surgical equipment (forceps, needle drivers and sterile scissors), anaesthesia (spinal preferred to general) for incision and availability of intravenous therapy (IV) comprising of fluids and antibiotics for post-operative care. CSs are often performed by medical officers, and availability of at least two is ideal for 24-hour operation. Nurses also provide critical skilled birth services before, during and after the procedure. Blood transfusion is recommended in case there are maternal complications such as haemorrhage.

### 4.3.2 Very Low Birthweight

In 2014, it was estimated that the country loses 89 newborns within their first months of life each day [Keats et al., 2018]. This translated to a neonatal mortality rate of 21 deaths per 1,000 livebirths. The main causes of deaths in the neonatal period were birth asphyxia (31.6%), prematurity (24.6%), sepsis (15.8%), congenital anomalies (13.8%) and acute respiratory infections (6.7%) [UNICEF, 2016]. Most of these deaths can be prevented by ensuring access to high-quality interventions including inpatient neonatal care, which estimates suggest can reduce neonatal deaths by 60% [Bhutta et al., 2014]. Important hospital services include oxygen for newborns born with respiratory distress syndrome, infant incubators, kangaroo mother care, intravenous provision of antibiotics for sepsis and assisted feeding for neonates born prematurely [Bhutta et al., 2014]. The highest risk of developing these conditions is in preterm / low birth weight (LBW) infants, who are often too small to maintain their body temperature, cannot feed actively or cannot breathe [Moxon et al., 2015]. This category requires careful monitoring by trained health professionals who understand the physiological and psychosocial needs of the baby [Bhutta et al., 2014].

Studies in Kenya have shown the role of low birthweight on neonatal mortality. NMR is high in children born with LBW (<2,500g), with a particularly elevated risk in those born in very low birthweight (VLBW; <1,500g) category [Ross & English, 2005; Aluvaala et al., 2015a]. A survey undertaken in neonatal wards of 22 public hospitals, found neonatal mortality to be highest in the VLBW category to be highest at 48%, compared to 13% in the LBW category, 10% in the normal weight category and 8% in the large for gestational age category [Aluvaala et al., 2015a]. Care for newborns in the VLBW category requires special wards with neonatal facilities, incubators, nurses, space for kangaroo mother care (KMC), feeding support using nasogastric and intravenous tubes in addition to oxygen provision and continuous positive airway pressure (Section 1.6.2). KMC is the process of providing continuous skin-to-skin contact between mother and newborn and exclusive breastfeeding, which lead to early discharge from hospitals. A survey in 2012 by Aluvaala et al., (2015) found the readiness of hospitals to provide a range of newborn hospital services for VLBW children to be wanting, with only nine of the 22 surveyed first level referral hospitals providing all these crucial services.

### 4.3.3 Policy Framework on Access to Maternal and Newborn Health Services

As shown in the previous section, provision of CS and care for infants born with VLBW will be key in reducing maternal and neonatal deaths in the country. Table 4.3, therefore, reviews the prioritization of geographic access within the Kenya policy framework, with a specific focus on comprehensive emergency obstetric and neonatal care. Eight documents spanning strategic plans, clinical guidelines and norms and standards for infrastructure were reviewed. Three documents identify the need to ensure geographic access to primary care as measured by population within 5 km of the nearest health facility. However, none of the documents provides a specific recommendation for measuring geographic access to emergency obstetric care in the country. However, timely access to emergency obstetric and neonatal care have been defined as two hours by the WHO guidelines on emergency obstetrics [WHO et al., 2009] and the Lancet Commission on Global Surgery [Meara et al., 2015]. Four African countries have gone ahead and adopted this time threshold, thus for Kenya, the same threshold can be used to define access to emergency CS and VLBW hospitals. The next section defines the methods used to determine hospitals that can offer these two services, how population in need of these services are determined and the process of defining accessibility to the hospital.

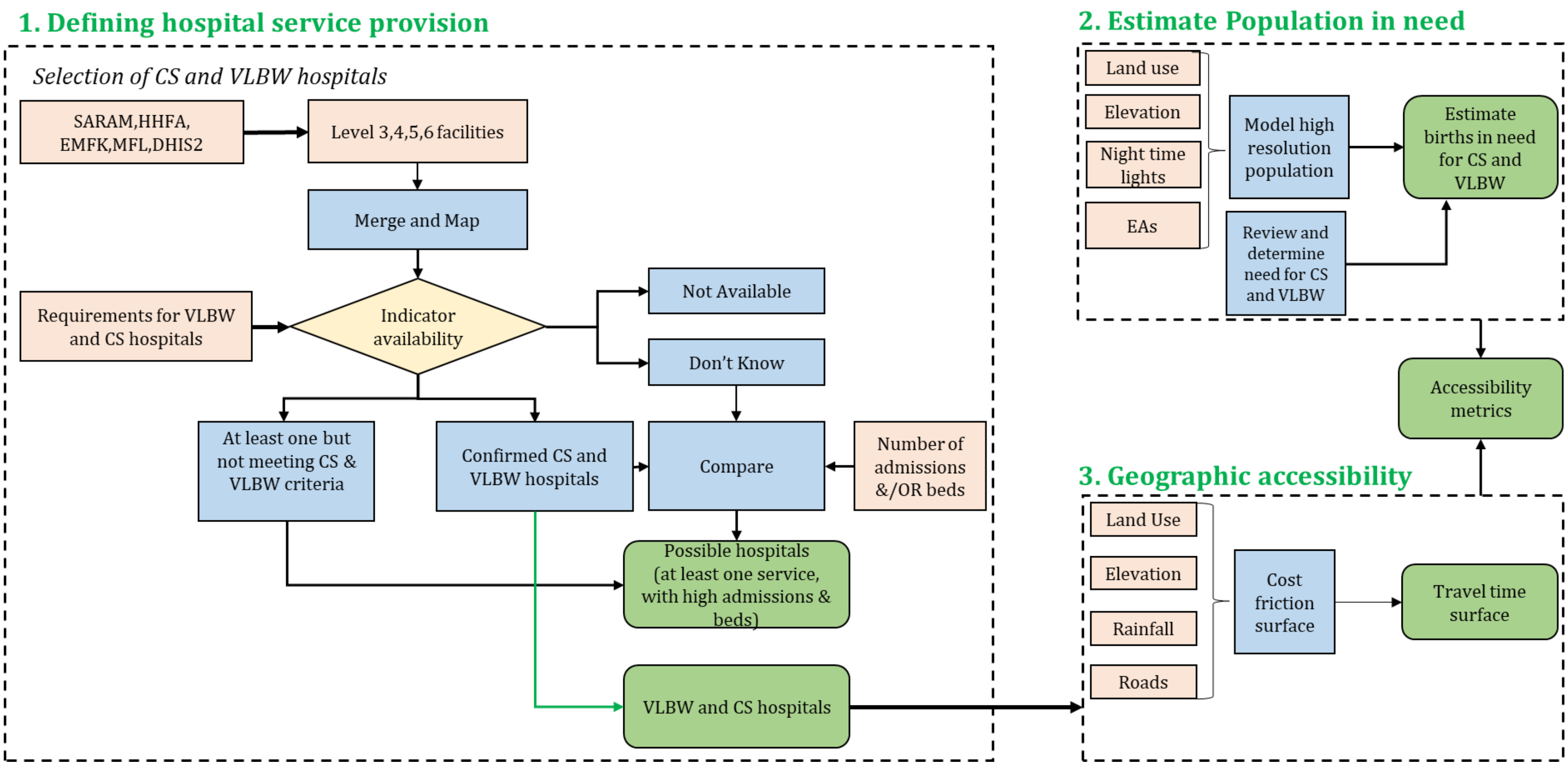
Table 4.3 Prioritization of geographic access within the Kenya maternal and newborn policy framework. The references are shown in the first column of each document.

| Document | Description | Provisions on Geographic access |
| --- | --- | --- |
| Clinical Guidelines for Management and Referral of Common Conditions at Levels 4–6: Hospitals [Ministry of Medical Services, 2009]. | Guides the specific services that should be provided for patients at level 4-6 hospitals. states that high-risk patients needing CS and LBW newborns should be managed at these levels. | No specific recommendations for geographic access to CEmONC |
| Kenya Vision 2030 [MoPD, 2007] | A multi-sectoral long-term policy aiming to move Kenya to a middle-income country providing high-quality services to the citizenry. | Emphasizes the need to ensure equity in access to health services care by 2030. |
| Kenya Health Policy 2014-2030 [MoH, 2014c] | Provides guidelines and direction for improving healthcare in-line with the constitution and Vision 2030, outlining the 6 key objectives. It outlines the 4 levels of the health service delivery system it envisions the country will have by 2030. | Identifies that all persons should be living within 5 km from a health service provider by 2030. No recommendation on access to obstetrics and neonatal care |
| Kenya Health Sector Strategic and Investment Plan 2014-2018 [MoH, 2014a] | The first strategic plan of the Kenya Health Policy 2014-2030, providing the medium-term focus for policy objectives, including an increase in access to the essential package of health by at least 90% | To ensure 90% of the population lives within 5 km of a health facility by 2018. No specific recommendations for geographic access to CEmONC |
| National Guidelines for Quality Obstetrics and Perinatal Care [MoH, 2011]. | A reference manual for delivery of perinatal and obstetric care aimed at improving practices. | Identifies the need for geographic access considerations including terrain and distances before as decisions are being made to refer mothers and newborns. No distance or time threshold defined. |
| Kenya Reproductive, Maternal, Newborn, Child and Adolescent Health (RMNCAH) Investment Framework 2016 [MoH, 2016] | Presentation of a set of prioritized interventions for investment and scale up over a five-year period to rapidly improve maternal, newborn and child health outcomes. | No thresholds for defining access to hospital services. No recommendations for geographic access to CEmONC |
| Kenya Health Sector Referral Strategy and Implementation Guidelines 2014 [MoH, 2014b] | Outlines the 6 levels of the health system and how patients move between the different levels. | No recommendations for geographic access to CEmONC |
| Health Infrastructure Norms and Standards [MoH, 2017]. | Provides guidance on planning for service delivery including infrastructure at different levels of care for attainment of UHC | 5Km is the distance threshold for primary care access. No specific recommendations for geographic access to CEmONC |
| The 2018-2022 UHC roadmap [MoH, 2018] | Spells out the UHC goal by 2022. It further provides strategic interventions and priority areas of implementation. | 100% of the population within 5Km of any health facility |

## 4.4 Methods

This section is divided into three main sub-sections. The first section (4.4.1), describes the process of assessing hospital capacity to provide services for VLBW and CS. The second section (4.4.2), describes the process used in estimating population in need of VLBW and CS services. The third section (4.4.3) is the methods used to define geographic access to the hospitals selected in Section 4.4.1 for the population in need derived in Section 4.4.2. The analytical workflow summarising all the steps is shown in Figure 4.8.

Figure 4.8 Analytical workflow for the Chapter. This is divided into three main sections worded in green with the major outputs in each section shown in dark green boxes. The light orange boxes are the data sources while the blue boxes are decision making steps or analytical processes.



### 4.4.1 Defining hospital service provision

This section aims to map hospitals that can provide CS and VLBW services in Kenya.

#### 4.4.1.1 Sources of Service Availability data

*Kenya Master Facility List (MFL)*

The master facility list (MFL) is in theory, a complete, authoritative, up-to-date inventory of health facilities [WHO, 2013]. It should include all the information needed to uniquely identify a facility, including the name, facility code/number, contact information, location attributes, administrative data and have the necessary information needed to identify facility type, ownership or operational status [USAID & WHO, 2018]. The Kenya Master Facility List (KMFL) managed by the Health Information Systems unit in the MoH is a dynamic resource and is supposed to contain all registered facilities in the country. Each health facility is identified by a unique identifier called the KMFL code. Additional information contained in the master facility list includes the administrative location (ward, sub-county, county), ownership or managing authority (whether private, faith-based or MoH), level of care (i.e. based on KePH service levels 1 to 6 defined in Table 4.1). The master facility list used in this analysis was downloaded on November 12th 2019 and contained 534 level 4,5 and 6 facilities [MoH-HIS, 2016].

*Service Availability and Readiness Assessment (SARAM)*

In 2013, the MoH with assistance from the WHO conducted a national Service Availability and Readiness Assessment Mapping (SARAM) survey that was based on the WHO Service Availability and Readiness Assessment (SARA) module [WHO, 2015c]. The Kenya SARAM survey covered both the public and private sector [GoK & WHO, 2014]. It had two main modules, an availability component which collected information on the physical presence of facilities and the resources offered in each surveyed facility, and a readiness component which collected information on the capacity to provide specific services. The SARAM was carried out between April and May in 2013, when the devolved system of governance in the country was coming into full adoption and was designed to provide baseline information for counties to know where gaps in service provision existed. At the time, 8,401 facilities were enumerated representing 88% of facilities in the country [GoK & WHO, 2014]. The SARAM reported 512 hospitals classified in either of the level 4,5 and 6 categories in the MFL.

*The District Health Information System (DHIS2)*

DHIS2 is currently the most commonly used system for routine health data collection, collation, management and reporting although reporting in the private for profit sector may not be adequate [Maina et al., 2017]. In Kenya, the system was first piloted in 2010 and after one year, it was launched nationally [HISP, 2017]. It is managed by the MoH and relies on health records officers who upload the facility-level data monthly. DHIS2 reports various indicators including treatments and outcomes at the facility level. Some of the data collected in the DHIS2 at facility level include the number of inpatient admissions by facilities, pints of blood transfused, laboratory services, inpatient mortality, number of caesarean deliveries among others. The period Jan 2017 to February 2018 was largely plagued by health worker strikes [Waithaka et al., 2020]hence data were extracted for 2016 only [DHIS2, 2018]. In total, there were 289 facilities in level 4,5 and 6 identified within the DHIS2 platform.

*The Kenya Harmonised Health Facility Assessment Data*

In 2018, the MoH conducted the Kenya Harmonised Health Facility Assessment (HHFA) in collaboration with development partners who provided both technical and financial support. The HHFA was conducted in readiness for the roll-out of the UHC drive launched in September 2018. The main aims of the HHFA were to fill critical data gaps in understanding health service availability and readiness of facilities to offer care, understand quality of care including adherence to standards and patient outcomes, and critically assess quality of care in the 4 pilot

UHC counties. It was also designed to provide reliable information on management of health facilities including financing, provide information on the functionality of the community structures to support UHC implementation. The HHFA employed additional modules to those in the SARA tool by adding those that collect information on financing, community structures and quality of care. The modules deployed in this exercise were;

- **Availability**: Information relating to the physical presence of facilities, resources, and
- **Readiness**: Capacity of a facility to provide specific services
- **Management & finance**: Practices to support continuous service availability and quality.
- **Quality & safety of healthcare**: Includes indicators of the receipt of appropriate, effective and timely care by patients under safe conditions.
- **Community Module**: A qualitative assessment of the community structures via key informant interviews with Community Health workers and focus group discussions with clients in all 47 counties

The HHFA was intended to provide county-level estimates using a sampling strategy to determine health facilities that could give the overall picture of county performance. The KMFL was used as the sampling frame where 10,512 facilities were drawn and included all types and ownership statuses. During the planning process for the exercise, several errors were identified in the MFL and these mainly comprised of misclassification of facilities (especially Level 4 hospitals), and were corrected by a technical working group comprising of the MoH and county health departments [MoH, 2019]. A final list of 412 hospitals was proposed which were selected to provide a complete picture of availability, readiness and quality of hospital-level services such as surgical care, comprehensive obstetric care, emergency care and other inpatient services.

*Emergency Medicine Foundation of Kenya (EMFK) Data*

Emergency Medicine Foundation of Kenya (EMFK) is a non-profit organisation based at the Aga Khan University, Kenya. Its main objective is to promote universal access to emergency care in Kenya. This is done through research into emergency care, development of policies and frameworks in conjunction with national and county governments aimed at fostering collaborations, promotion of emergency medical education and partnerships [EMFK, 2019]. One of the projects that EMFK undertook in 2018 was to assess the capacity, readiness and ability of public hospitals (both government and mission hospitals) to provide emergency surgical services in Kenya. Information on equipment, human resource and adherence to surgical guidelines were collected in county-level surveys conducted between 2018 and 2019 [EMFK Project-47, 2019]. Each counties' health department/ministry heads were asked to provide information on all the facilities they considered level 4,5 or 6. Those with functional theatres were then selected for a detailed assessment of ability and readiness to provide a range of emergency surgical services [EMFK Project-47, 2019]. As of January 2019, data cleaning and verification had only been done for 23 counties, and these were availed through personal communication with EMFK. All the data sources are summarised in Table 4.4.

Table 4.4 Summary of sources of hospital data, the years they represent, their scope and availability status. Those not publicly available have been provided through personal communication.

| **Source** | **Year** | **Number of hospitals** | **Scope** | **Data availability** | **Citation** |
|---|---|---|---|---|---|
| MFL | 2018 | 534 | Reports on the health facilities available | Publicly available | [MoH-HIS, 2016] |
| SARAM | 2013 | 512 | Service availability for all Facilities in Kenya | Not publicly available | [GoK & WHO, 2014] |
| EMFK | 2018 | 119 | Service availability all government hospitals with a functioning theatre | Not publicly available | [EMFK Project-47, 2019] |
| HHFA | 2018 | 412 | Service availability for sample facilities but included all hospitals | Not publicly available | [MoH, 2019] |
| DHIS 2 | 2016 & 2018 | 289 | Reporting rates for all hospitals | Available on request | [DHIS2, 2018] |

These datasets were collected at different time points and in some instances, there were discrepancies in reported indicators. This necessitated a process of merging the different layers to generate a single database of facilities and services provided. In addition, assessment of CEmONC service availability was done for all facilities classified as level 4, 5 and 6 in any of the datasets and those reporting admissions in the DHIS2.

*Merging the data sources*

A single database of facilities including the services they provide was created using a combination of the data sources in the previous section. In some cases, information on service availability was conflicting, and a process of reconciling the differences was undertaken. SARAM was chosen as the baseline because it is the oldest dataset. If a facility had the service available in the SARAM, it was adopted. Otherwise, its availability status was cross-checked with information from the EMFK and HHFA datasets. If the two more current databases showed discordance with the SARAM, those from the EMFK and or the HHFA were adopted. This was to handle cases where services may have been available historically but were no longer available in subsequent periods. For example, if a hospital was reported to have functional X-Ray machine when the SARAM was conducted in 2013 but was not available when the HHFA and EMFK surveys were conducted, the information was updated. A similar process was undertaken for services reported not to be available.

Facilities with no information on whether services were available or not were labelled as don't know. This list was then merged with the admissions list obtained from DHIS 2 to have for each facility the number of admissions. The ownership status of each facility was recorded as either MoH – those owned by either the national or county governments, Other public – those owned by the government but provide services to specialised groups like the military or institutions, faith-based organisations (FBO), Non-governmental organisations or private facilities. Coordinates were obtained from the databases, which all used the gold standard GPS mapping technique, but in cases where coordinates were not available, then geocoding was undertaken using methods described elsewhere [Maina et al., 2019]. In brief, 1981 facilities were obtained, with 462 (23%) containing GPS coordinates from the original datasets. The remaining 1518 (77%) were assigned longitude and latitude from google earth. While mapping, all facilities were checked to ensure they were falling within their predefined administrative units. In addition, they were checked to ensure none were falling within parks and water bodies.

#### 4.4.1.2 Assessment for CEmONC Service Availability

The merged facility list was used to assess facility capability to provide CEmONC services. Based on what is needed to offer services for the two tracer conditions as described in Section 4.3, the availability of the following services/indicators (Table 4.5) were extracted for each hospital. CEmONC often identifies neonatal resuscitation which was only collected in the HHFA. When these facilities were checked, they all had an infant incubator and oxygen services and the two services was used for the other datasets. The merged hospital list therefore contained information on whether the services were available, not available or whether the status of services could not be ascertained (don't know). The indicators above were used to select hospitals. In the first step, confirmed hospitals were identified as those that provide six main tracer indicators required for providing CS and VLBW services. These were availability of an operating theatre with surgical equipment, oxygen, blood transfusion, infant incubator, x-ray and having at least two medical officers (Table 4.5). The aim of identifying the confirmed hospitals, was so that they could be used in selecting facilities that could have been missed in the surveys using a different source of data, as described in the next section. In addition, facilities that do not meet the confirmed hospitals criteria but offer either CS and VLBW services were also identified.

Table 4.5 Indicators used to select service availability at hospitals from the EMFK, HHFA and SARAM. The orange areas are those needed for VLBW service, green are those needed for CS services and blue are those needed for both tracer conditions.

| **Indicator** | **SARAM (2013)** | **EMFK (2018)** | **HHFA (2018)** |
|---|---|---|---|
| Availability of at least two registered nurses, who presumably provide critical KMC. KMC only available in HHFA | Reports number of nurses in each facility. Includes a separate category of registered nurses | No data | Reports number of nurses in each facility. Includes a separate category of registered nurses |
| Availability of at least two medical officers | Reports the number of medical officers in each facility. | Reports whether there are medical officers providing emergency surgery | Reports the number of medical officers in each facility. |
| Chest x-ray services offered | Whether available or not | No data | Whether available only. No unavailability data |
| Intravenous fluids (IV fluids) available | Whether available only. No unavailability data | No data | Whether available or not |
| Oxygen Services | Whether available or not | No data | Whether available or not |
| Infant incubator | Whether available or not | No data | Whether available or not |
| Operating theatre | Whether available or not | Whether available or not | Whether available or not |
| Blood transfusion services | Whether available or not | Whether available or not | Whether available or not |
| Availability of basic surgical equipment. Includes a theatre bed, instruments for incision (forceps, needle driver and sterile scissors), anaesthetic machine and infection prevention control. | Whether available only. No unavailability data | No data | Whether available only. No unavailability data |

Capacity can be identified using both the number of admissions and the number of beds. Thus, the median number of admissions and beds in the confirmed hospitals was calculated. Facilities with at least one tracer indicator of the six available, not meeting CS or VLBW criteria and having median values higher than the value calculated from confirmed hospitals were identified as possible hospitals. The list of all CS and VLBW hospitals (including the confirmed) was used to define geographic access to CS and VLBW care. In addition, all the facilities including the possible hospitals were used to create a scenario of access to all hospitals in Kenya. The next section, therefore, describes the process of mapping the subset of the population that requires these services.

### 4.4.2 Mapping Population in Need of CS and VLBW Services

Defining accessibility to health facilities in a cost distance framework requires an understanding of population distribution at fine spatial resolution. In Chapter 2, gridded population data from the WorldPop was used, with the process of modelling the surfaces described in detail elsewhere [Tatem et al., 2013; Sorichetta et al., 2015; Lloyd et al., 2017; Pezzulo et al., 2017]. In brief, a dasymetric modelling technique [Mennis, 2009], was used to redistribute population counts from sub-Location data to 100m square grids [Stevens et al., 2015]. To assist in the re-distribution, several covariates including proximity to roads and health facilities were used. This population layer had some limitations.

Because the model clusters populations around health facilities and roads, then circularity is introduced if population output is used in modelling geographic access. In Kenya, two covariates were used to redistribute population counts health facilities and roads [Stevens et al., 2015], introducing circularity in health facility accessibility models that additionally use roads. In addition to circularity the use of total number of WoCBA misrepresents the actual need, since only a fraction of births would be expectant and need emergency obstetric and neonatal care. Therefore, in this Chapter, population data which relies only on highly disaggregated input census data without adjusting for proximity to roads or health facilities at 100m spatial resolution was modelled using methods previously used by the Worldpop [Alegana et al., 2020]. This layer was used to estimate number of births needing caesarean sections and VLBW using information on potential need from literature and several data sources.

#### 4.4.2.1 Mapping total population and births

To model total population surface enumeration areas (EA) were used. EAs are the smallest census units used during the enumeration exercise and is often equivalent to villages. The 54,000 EAs used in the 2009 census were used. To obtain a 2019 population estimate, the 2009 EAs were matched to the 2019 population census boundaries and the intercensal growth rates between 2009 and 2019 used to obtain 2019 population. A random forest algorithm was then used to redistribute the population counts within each EA according to different land covers, elevation or night-time light intensities. The modelled population was then used to derive estimates of livebirths using crude birth rates obtained from the 2009 census at county level [KNBS, 2010]. The births surface was subsequently used to derive the need for both CS and VLBW services using methods and datasets described in the next section.

#### 4.4.2.2 Estimating the Population Needing Caesarean Deliveries

The next step was aimed at estimating the proportion of births that would need CS. Based on a systematic review of ecological studies conducted by the WHO, it was established that at community levels, at least 10% of the births would be complicated enough to need CS. The choice of threshold was based on the observed reduction in maternal and newborn deaths with increasing rates of CS up to a 10% CS rate when the relationship levels [Ye et al., 2016]. Thus, the livebirths population was multiplied by 0.1 to obtain population needing CS.

#### 4.4.2.3 Newborns in Need of VLBW Hospital Services

Three main data sources were used to derive the proportion of births that need VLBW services.

i. A literature review of studies reporting the prevalence of VLBW in Kenya, PubMed search terms that extract studies reporting birthweights in Kenya and these were;

“*low birth weight OR very low birth weight OR *weight OR birth* OR *weight OR VLBW or LBW OR 1500 kg OR 1.5 Kg) AND (Kenya) AND (newborns)*”

The article extraction flow diagram is shown in the Appendix 2. Several indicators were used to judge the quality of the studies and to estimate the weights used in calculation of the averages [Borges Migliavaca et al., 2020]. First, was whether the study reported that only registry data were used to obtain weight measurements. The second was if both VLBW numbers and total births in the facility was reported. Lastly, was whether it was recorded that weight measurements were taken within the first one hour of birth as after this period, newborns experience significant weight gains [Karim et al., 2018]. Thus, having met all three criteria meant a weight of 1, those with two weighted 0.67, the ones meeting only one weighted 0.33 and the calculation of mean VLBW prevalence accounted for these weights.

ii. Two Health and Demographic Surveillance Systems (HDSS)

The two HDSS datasets used were; Kilifi Health and Demographic Surveillance System (KHDSS) [Scott et al., 2012], and the Nairobi Urban Health and Demographic Surveillance System (NUHDSS) [Beguy et al., 2015]. The HDSS is a platform for investigating the health of individuals within a specific area, often serving as sources of data for studies evaluating the impacts of interventions. The number of children born and their characteristics including weight are normally enumerated at the household level. The Kilifi HDSS data was obtained through the KEMRI-Wellcome Trust internal data request process, while summaries from the NUHDSS was obtained from the published data from the NUHDSS [Mutua et al., 2015].

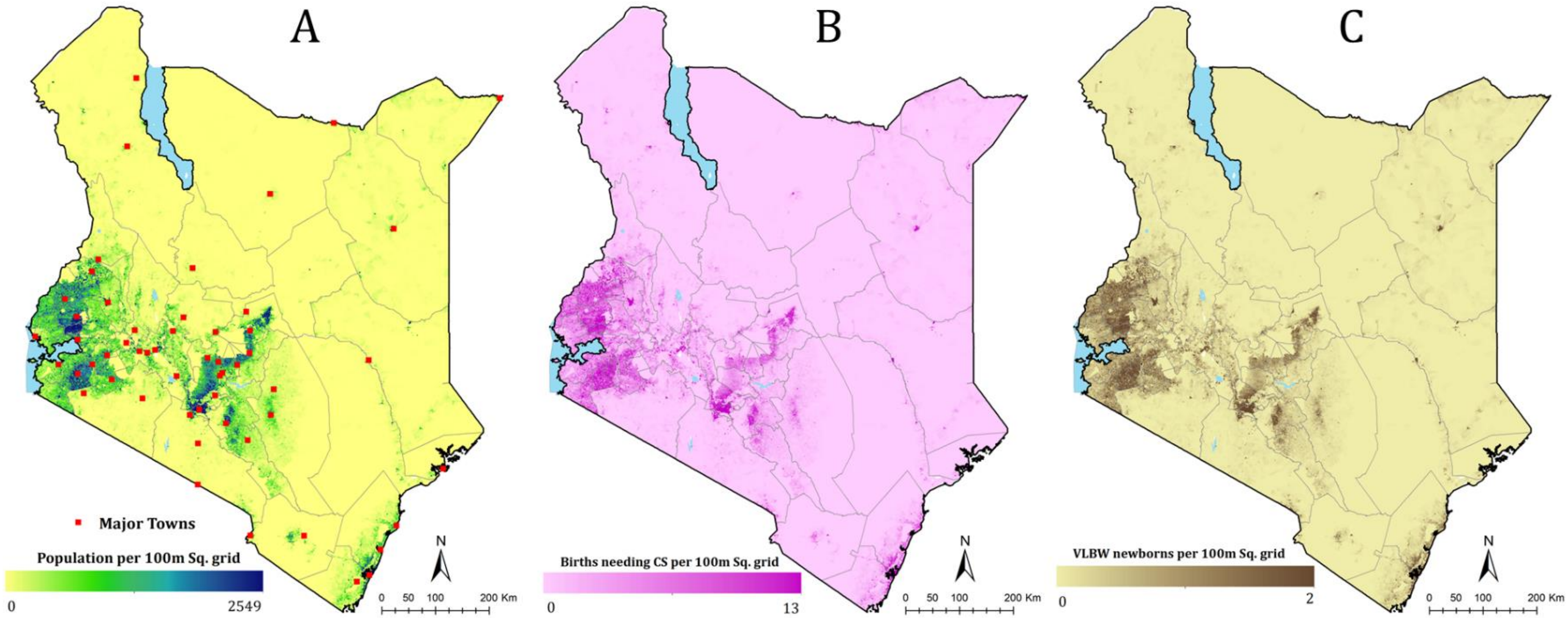
iii. Extracting same numbers from the Clinical Information Network (CIN)

The CIN is a collaboration between public hospitals, policymakers and researchers and aims to improve availability of information on the quality of inpatient paediatric care [Ayieko et al., 2011]. In April 2018, the CIN started collecting data on inpatient neonatal care and this included preterm births admitted to the newborn wards. Information on birthweights was therefore reported and those born with VLBW were extracted for 16 hospitals with data. Summaries of data sources are shown in Appendix 3. VLBW prevalence was therefore calculated by multiplying the proportion of VLBW births with the total number of births surface.

A total of 111,351 births were extracted from all the studies of which 2,342 were VLBW. From each study, prevalence of VLBW varied from 0.80% in the DHS data to 3.16% in CIN hospital 9. All sources were obtained from registry data/birth cards. None of the sources from CIN reported total facility births and these had to be obtained from DHIS2. In four sources, it was not possible to determine whether birthweights were obtained within one hour of birth as shown in Appendix 3. The calculated prevalence of 0.011 was therefore applied to the births surface to determine those in need of VLBW services

A visual inspection shows that most births were occurring in areas around Nairobi, the central highlands including regions around Mount Kenya, and the western part of the country (Figure 4.9). Densely populated areas were also observed in regions circa 60 km from the coastline. Northern and North Eastern Kenya are relatively sparsely populated but there are pockets of densely populated areas particularly around major towns and refugee camps. In 2018, there were an estimated 212,350 births needing emergency CS. Majority were in Nairobi, where approximately 17,837 women may have needed emergency CS. The counties with fewest expected number of women requiring emergency CS were Lamu and Isiolo, both accounting for less than 1% if the national CS burden. Using the empirical evidence of VLBW births, it is estimated that in 2018 29,725 live births were born of VLBW in Kenya with similar distributions to those of CS at county levels. The distribution of total population, and those needing CS and VLBW services are shown in Figure 4.9. It is worth noting that since proportions which are not spatially varying were used, the distribution of such populations are similar.

Figure 4.9 Distribution of A) Population distribution in Kenya in 2018 showing increasing numbers from yellow to dark blue regions. The red dots represent major towns in the country B) Births requiring caesarean deliveries with increasing numbers from light pink to dark pink. C) Newborns requiring VLBW services with increasing numbers from light brown to dark brown



### 4.4.3 Modelling geographic access to CEmONC services

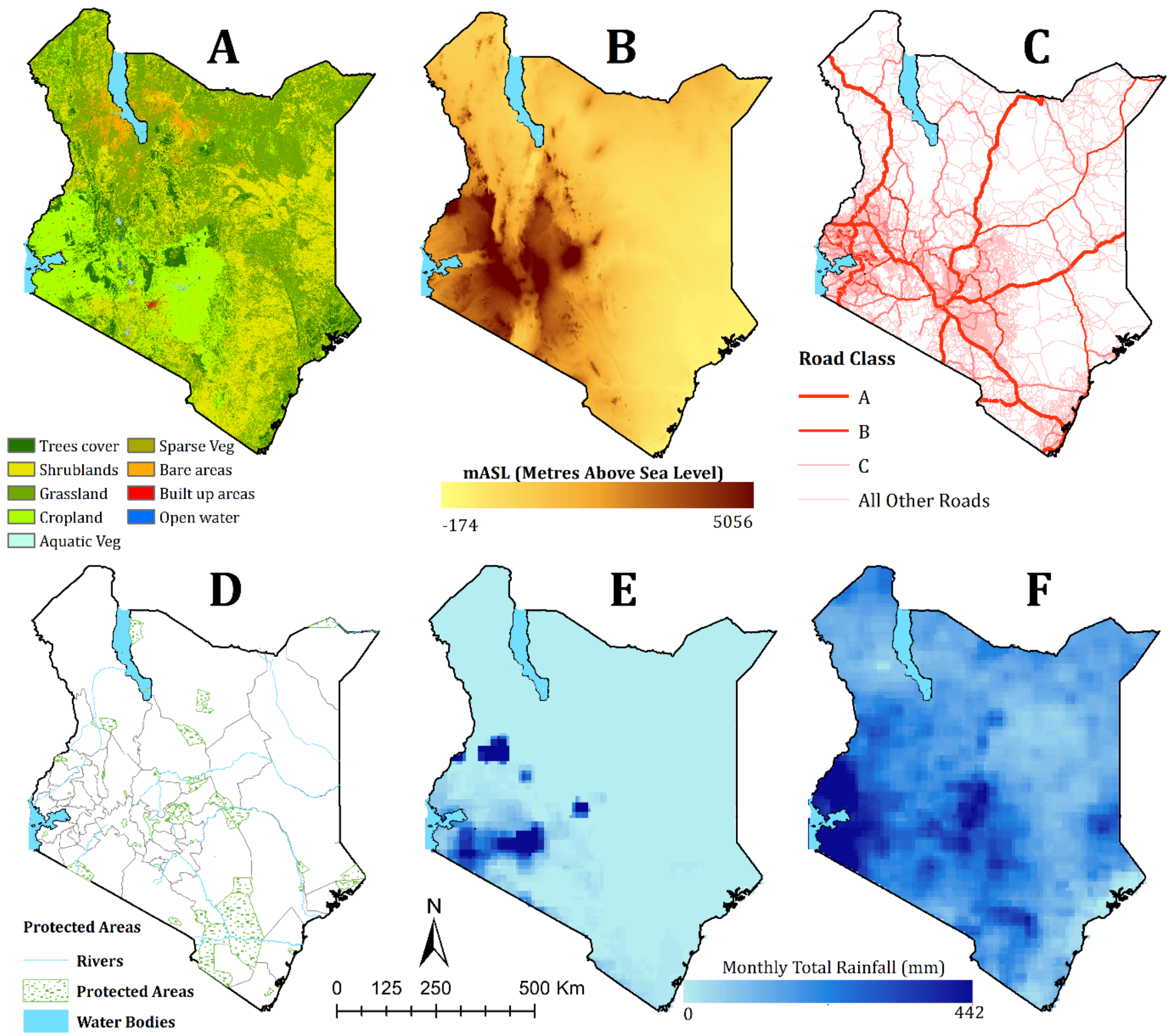
#### 4.4.3.1 Covariates used in modelling geographic access

This section describes the use of a cost distance model to define geographic access to CS and VLBW hospitals (assembled in Section 4.4.1) for the population in need (assembled in Section 4.4.2). The accessibility model corrects for various landscape factors that act as either enablers or barriers towards travelling to health facilities. These are land use, elevation, roads, weather variation, water bodies and protected areas. Sources of these datasets including their spatial resolution and other specifications are summarised in Table 4.6 and mapped in Figure 4.10.

Table 4.6 Covariates used in modelling spatial accessibility including their type, sources and spatial resolution.

| **Data Layer** | **Format** | **Spatial resolution** | **Purpose** | **Source** |
|---|---|---|---|---|
| Land Use | Raster | 20m | Provide land feature classes (i.e., forestland, grassland, cropland, settlement, wetland) | sentinel 2 satellite sensor was downloaded from (https://www.rcmrd.org/) |
| Elevation | Raster | 30m | To define slope used for adjustment of walking speed | Shuttle Radar Topography Mission downloaded from (http://gdex.cr.usgs.gov/gdex/) |
| Rainfall | Raster | 1000m | Provide rainfall estimates used to adjust speed in wet period for roads affected. | Rainfall Estimation (RFE) downloaded from (http://earlywarning.usgs.gov/fews/product/119#download). |
| Roads | Vector | NA | Provide road networks where motorized transport is enabled. With road classed defined in Appendix 4 | Ministry of Transport, Infrastructure, Housing & Urban Development maps digitised |
| Protected Areas | Vector | NA | Provide a layer of barrier to travel | KWS and KFS obtained from (http://biodiversityatlaskenya.org/bio-geoportal/) |
| Water bodies (Rivers and lakes) | Vector | NA | Provide layers of barriers to travel | Global Lakes and Wetlands Database from (http://www.worldwildlife.org/pages/global-lakes-and-wetlandsdatabase) |

Figure 4.10 A) Kenya land uses as shown in different colours. B) Digital elevation model showing increasing elevation from light brown to dark brown. C) Kenya road network showing the different classes. Detailed description of the road classes is found in Appendix 4. D) Shows the barriers to travel i.e, protected areas, lakes and river. E) Shows rainfall estimates in the driest month of January while F) Shows rainfall distribution in the wettest month of April.



#### 4.4.3.2 Creating a cost friction surface

In deriving the cost friction surface, all the vector layers were converted to rasters, and their spatial resolution matched to the land cover grid that was resampled to 100m spatial resolution. For the roads classified as A, B or C, motorized transport was assumed. Along tertiary classified roads, it was assumed that motorcycle transport which is a significant mode of transport in Kenya was adopted. Travel speeds across different land covers and road segments were used to create a cost friction surface. A cost friction surface defines the ease of crossing each square grid and is a function of the grid size and speed of travel. Motorised speeds for highways and urban roads were obtained from the traffic act and others calibrated by the Kenya roads board using roads speeds collected during the GPS mapping exercise. Walking speeds across different land use classes were obtained from previous studies in Kenya [Dellicour et al., 2017] and are shown in detail in Appendix 5. Barriers to transport (major rivers, water bodies and forests) were assigned zero speeds. The influence of slope on walking speeds was accounted for by the Tobler's hiking equation, that indicates how slope affects speeds (Section 1.6.3), while the neighbourhood was set at 16 as described in the modified Moore representation (Section 1.6.2).

#### 4.4.3.3 Accessibility model

Accessibility was computed to the CS and VLBW hospitals. The models were run for different months to account for the influence of seasonal weather conditions. To define inability to use road transport areas where monthly rainfall exceeded 60mm, the speed within roads in poor conditions was assumed to be reduced by between 70 and 80% based on calibrated values from a previous study [Makanga et al., 2017]. Therefore, temporal maps of access to each hospital were produced. The analysis was conducted in R version 3.0 using the gdistance package [van Etten, 2017]. The cost distance model was implemented like the one described in Section 2.3.2

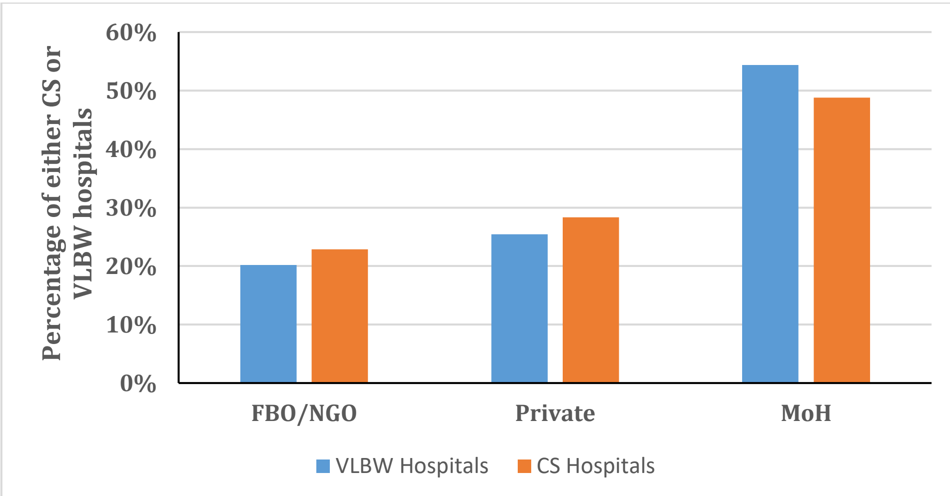
where a composite model of both non-motorised and motorised transport was assumed. The model was run assuming patients would travel between counties with access computed as a continuous process. To define accessibility, the two-hour threshold was used and population within these catchments summarised at county levels. A sensitivity analysis was done using the 1 hour travel time. Accessibility quotients at different time thresholds were also extracted to define distance decay graphs. The lowest and highest travel times are mapped to demonstrate areas where access is consistently good, are poor or vary by seasons.

## 4.5 Results

### 4.5.1 CS and VLBW service availability

Based on extraction of the six core indicators, 598 facilities with at least one of the tracer services were identified. Overall, specific services, 408 facilities had a theatre, 351 had an infant incubator, 302 with X-Ray services, 435 with oxygen, 440 with blood transfusion services and 369 with at least two medical officers. In total, there were 201 confirmed hospitals providing all the six core indicators and therefore considered to offer both CS and VLBW care. The highest numbers of confirmed hospitals were in Kisumu (n=10), Kiambu (n=14) and Nairobi (n=20). On the other hand, Elgeyo Marakwet, Isiolo, Nyamira, West Pokot and Tana River had only one confirmed hospital each. There were different combinations of service availability across the hospitals. For example, of the facilities with an operating theatre, 356 had blood transfusion available, while 260 had access to X-Ray. On the other hand, of the 351 with an infant incubator, 297 had oxygen available during the survey, while 238 had X-ray Services. This shows that there were variations in service availability across the hospitals thus affecting provision of care. There were additional 92 and 27 facilities that were not in the confirmed category but fulfilled the criteria for CS and VLBW service provision separately. Thus, there were 293 CS specific and 228 facilities had both VLBW and CS services. Majority of services are provided by the MoH as shown in Figure 4.11 followed by the private sector and the FBOs or NGOs. The specific hospital numbers by ownership category and county are shown in Appendix 6.

Figure 4.11 CS and VLBW service availability by facility ownership category

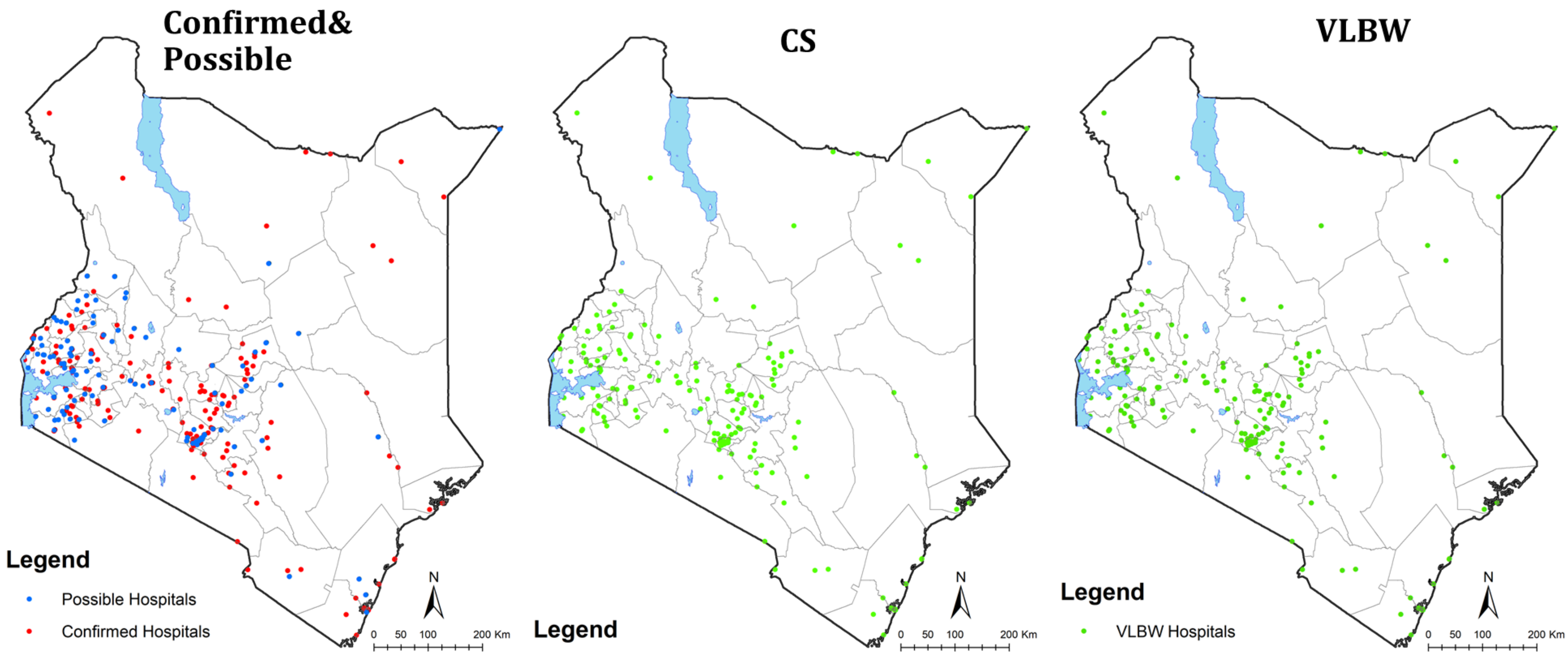



These hospitals were mainly located in Nairobi (n=24), Kiambu (n=17), Nakuru (n=15), Mombasa (n=15), Kisumu (n=13) and Kisii (n=13). Counties with few CS hospital numbers were Isiolo and Nyamira having only one CS hospital each. Counties with high numbers of CS hospitals were also Nairobi (n=22), Nakuru (n=11), Kisumu (n=12) and Kiambu (n=17), while Embu, West Pokot, Tana River and Isiolo had only one VLBW hospital. Distribution of these hospitals is shown in Table 4.7 and Figure 4.12. The median number of beds in the confirmed hospitals was 40 while the number of admissions was 1,100 and this threshold was used to define 112 possible hospitals. Possible hospitals were those with at least one tracer indicator of the six available, not meeting CS or VLBW criteria and had median values higher than the value calculated from confirmed hospitals. In total, there were 431 hospitals that includes all the CS, VLBW and possible hospitals.

Table 4.7 Numbers of confirmed, possible, CS and VLBW hospitals individually. Total number of hospitals are also shown. Percentages are calculated for the total number of hospitals.

| County | Confirmed [%] | CS [%] | VLBW [%] | Possible [%] | Total |
|---|---|---|---|---|---|
| Baringo | 2 [40%] | 1 [20%] | 0 [0%] | 2 [40%] | 5 |
| Bomet | 2 [50%] | 1 [25%] | 0 [0%] | 1 [25%] | 4 |
| Bungoma | 5 [38%] | 4 [31%] | 0 [0%] | 4 [31%] | 13 |
| Busia | 5 [56%] | 0 [0%] | 0 [0%] | 4 [44%] | 9 |
| Elgeyo Marakwet | 1 [17%] | 1 [17%] | 1 [17%] | 3 [50%] | 6 |
| Embu | 1 [17%] | 4 [67%] | 0 [0%] | 1 [17%] | 6 |
| Garissa | 2 [40%] | 2 [40%] | 1 [20%] | 0 [0%] | 5 |
| Homa Bay | 4 [40%] | 2 [20%] | 1 [10%] | 3 [30%] | 10 |
| Isiolo | 1 [50%] | 0 [0%] | 0 [0%] | 1 [50%] | 2 |
| Kajiado | 4 [67%] | 2 [33%] | 0 [0%] | 0 [0%] | 6 |
| Kakamega | 4 [24%] | 2 [12%] | 2 [12%] | 9 [53%] | 17 |
| Kericho | 8 [73%] | 0 [0%] | 1 [9%] | 2 [18%] | 11 |
| Kiambu | 14 [50%] | 3 [11%] | 3 [11%] | 8 [29%] | 28 |
| Kilifi | 4 [57%] | 1 [14%] | 1 [14%] | 2 [29%] | 7 |
| Kirinyaga | 4 [67%] | 1 [17%] | 0 [0%] | 1 [17%] | 6 |
| Kisii | 8 [44%] | 5 [28%] | 0 [0%] | 5 [28%] | 18 |
| Kisumu | 10 [48%] | 3 [14%] | 2 [10%] | 6 [29%] | 21 |
| Kitui | 4 [36%] | 2 [18%] | 3 [27%] | 2 [18%] | 11 |
| Kwale | 2 [67%] | 1 [33%] | 0 [0%] | 0 [0%] | 3 |
| Laikipia | 3 [38%] | 3 [38%] | 0 [0%] | 2 [25%] | 8 |
| Lamu | 2 [67%] | 1 [33%] | 0 [0%] | 0 [0%] | 3 |
| Machakos | 5 [56%] | 2 [22%] | 1 [11%] | 1 [11%] | 9 |
| Makueni | 5 [63%] | 2 [25%] | 0 [0%] | 1 [13%] | 8 |
| Mandera | 3 [60%] | 1 [20%] | 0 [0%] | 1 [20%] | 5 |
| Marsabit | 3 [60%] | 1 [20%] | 0 [0%] | 1 [20%] | 5 |
| Meru | 8 [53%] | 2 [13%] | 1 [7%] | 4 [27%] | 15 |
| Migori | 4 [27%] | 5 [33%] | 0 [0%] | 6 [40%] | 15 |
| Mombasa | 9 [56%] | 6 [38%] | 0 [0%] | 1 [6%] | 16 |
| Murang'a | 4 [50%] | 4 [50%] | 0 [0%] | 0 [0%] | 8 |
| Nairobi | 20 [56%] | 4 [11%] | 2 [6%] | 10 [28%] | 36 |
| Nakuru | 8 [35%] | 7 [30%] | 3 [13%] | 5 [22%] | 23 |
| Nandi | 3 [43%] | 2 [29%] | 0 [0%] | 2 [29%] | 7 |
| Narok | 3 [60%] | 1 [20%] | 0 [0%] | 1 [20%] | 5 |
| Nyamira | 1 [25%] | 0 [0%] | 2 [50%] | 1 [25%] | 4 |
| Nyandarua | 2 [67%] | 1 [33%] | 0 [0%] | 0 [0%] | 3 |
| Nyeri | 7 [64%] | 2 [18%] | 1 [9%] | 1 [9%] | 11 |
| Samburu | 2 [100%] | 0 [0%] | 0 [0%] | 0 [0%] | 2 |
| Siaya | 4 [33%] | 2 [17%] | 0 [0%] | 6 [50%] | 12 |
| Taita Taveta | 3 [50%] | 1 [17%] | 1 [17%] | 1 [17%] | 6 |
| Tana River | 1 [33%] | 1 [33%] | 0 [0%] | 1 [33%] | 3 |
| Tharaka Nithi | 2 [33%] | 2 [33%] | 0 [0%] | 2 [33%] | 6 |
| Trans Nzoia | 3 [38%] | 1 [13%] | 0 [0%] | 4 [50%] | 8 |
| Turkana | 2 [50%] | 2 [50%] | 0 [0%] | 0 [0%] | 4 |
| Uasin Gishu | 4 [44%] | 2 [22%] | 1 [11%] | 2 [22%] | 9 |
| Vihiga | 2 [40%] | 0 [0%] | 0 [0%] | 3 [60%] | 5 |
| Wajir | 2 [67%] | 1 [33%] | 0 [0%] | 0 [0%] | 3 |
| West Pokot | 1 [25%] | 1 [25%] | 0 [0%] | 2 [50%] | 4 |
| **Total** | **201 [47%]** | **92 [21%]** | **27 [6%]** | **112 [26%]** | **431** |

Figure 4.12 Distribution of confirmed, possible, CS and VLBW hospitals in Kenya




**Footnote:** Confirmed hospitals are those providing all the services. Possible hospitals are those with at least one tracer indicator of the six available, not meeting CS or VLBW criteria and having median values higher than the value calculated from confirmed hospitals. There are CS and VLBW hospitals that are not confirmed hospitals and all of these hospitals are shown separately.

### 4.5.2 Population in need of CS and VLBW services

At 4.95 million, Nairobi was the most populated county, while the least populated was Lamu. As estimates of prevalence of both CS and VLBW were not varying at sub-national levels, distribution of births at pixel levels mirrored that of the total population. County-level estimates are shown in Table 4.8. The population estimates were also linked to the number of facilities. This was done based on the recommendation of facility to population ration (FPR) of 1 CEmONC facility per 500,000 population for defining accessibility [WHO et al., 2009]. All the counties had more than 1 facility for every 500,000 population in the CS analysis. In the VLBW analysis, only Embu county had more than 500,000 people per facility. Based on the FPR, access was highest in counties such as Kericho, Kiambu, Kisumu, Lamu, Marsabit, Nyeri, Samburu and Taita Taveta all with less than 100,000 persons per facility in both the VLBW and CS analysis. County-level metrics for FPR are shown in Table 4.8. As described in the literature review section 1.7.1, facility to population ratios can be limiting when describing geographic access, as populations use services across county boundaries, and the next section describes the results of the accessibility modelling using cost distance analysis.

Table 4.8 Aggregated estimates of total population, livebirths, stillbirths, livebirths needing emergency CS, newborns with VLBW and FPRs at county level. All estimates are for 2018.

| County | Total Population | Livebirths | Livebirths needing CS | Livebirths needing VLBW | FPR (CS) | FPR (VLBW) |
|---|---|---|---|---|---|---|
| Baringo | 727,417 | 33,388 | 3,339 | 467 | 180,168 | 270,252 |
| Bomet | 1,133,727 | 52,378 | 5,238 | 733 | 299,063 | 448,594 |
| Bungoma | 1,998,938 | 93,550 | 9,355 | 1,310 | 168,031 | 302,455 |
| Busia | 985,867 | 46,533 | 4,653 | 651 | 149,170 | 149,170 |
| Elgeyo-Marakwet | 476,095 | 20,853 | 2,085 | 292 | 186,694 | 186,694 |
| Embu | 620,846 | 20,364 | 2,036 | 285 | 108,489 | 542,443 |
| Garissa | 821,048 | 42,448 | 4,245 | 594 | 151,152 | 201,536 |
| Homa Bay | 1,167,635 | 62,702 | 6,270 | 878 | 161,092 | 193,311 |
| Isiolo | 200,664 | 8,448 | 845 | 118 | 143,830 | 143,830 |
| Kajiado | 787,623 | 49,778 | 4,978 | 697 | 80,019 | 120,028 |
| Kakamega | 2,293,132 | 102,732 | 10,273 | 1,438 | 305,184 | 305,184 |
| Kericho | 614,335 | 33,358 | 3,336 | 467 | 61,320 | 54,506 |
| Kiambu | 1,838,358 | 71,144 | 7,114 | 996 | 82,551 | 82,551 |
| Kilifi | 1,462,478 | 68,736 | 6,874 | 962 | 221,285 | 221,285 |
| Kirinyaga | 600,675 | 16,098 | 1,610 | 225 | 104,964 | 131,205 |
| Kisii | 1,422,800 | 63,172 | 6,317 | 884 | 91,417 | 148,553 |
| Kisumu | 1,212,277 | 54,674 | 5,467 | 765 | 77,193 | 83,626 |
| Kitui | 1,243,189 | 53,208 | 5,321 | 745 | 169,979 | 145,696 |
| Kwale | 808,950 | 38,425 | 3,843 | 538 | 209,584 | 314,376 |
| Laikipia | 571,026 | 20,728 | 2,073 | 290 | 77,376 | 154,752 |
| Lamu | 121,069 | 3,995 | 400 | 56 | 29,188 | 43,782 |
| Machakos | 1,418,766 | 63,986 | 6,399 | 896 | 169,293 | 197,509 |
| Makueni | 1,140,307 | 41,279 | 4,128 | 578 | 143,616 | 201,062 |
| Mandera | 716,735 | 39,349 | 3,935 | 551 | 123,892 | 165,190 |
| Marsabit | 358,047 | 16,255 | 1,626 | 228 | 56,057 | 74,743 |
| Meru | 1,660,709 | 58,623 | 5,862 | 821 | 137,471 | 152,746 |
| Migori | 1,285,034 | 66,179 | 6,618 | 927 | 101,425 | 228,206 |
| Mombasa | 1,268,333 | 47,055 | 4,706 | 659 | 60,064 | 100,106 |
| Murang'a | 1,003,693 | 23,587 | 2,359 | 330 | 121,025 | 242,051 |
| Nairobi | 4,954,635 | 178,367 | 17,837 | 2,497 | 142,740 | 155,716 |
| Nakuru | 2,125,299 | 85,437 | 8,544 | 1,196 | 107,192 | 146,170 |
| Nandi | 1,002,211 | 43,095 | 4,310 | 603 | 155,793 | 259,654 |
| Narok | 1,093,140 | 56,078 | 5,608 | 785 | 179,023 | 238,698 |
| Nyamira | 592,925 | 33,500 | 3,350 | 469 | 499,730 | 166,577 |
| Nyandarua | 834,716 | 29,883 | 2,988 | 418 | 224,187 | 336,280 |
| Nyeri | 744,787 | 27,408 | 2,741 | 384 | 77,701 | 87,414 |
| Samburu | 237,522 | 11,354 | 1,135 | 159 | 75,726 | 75,726 |
| Siaya | 923,160 | 42,742 | 4,274 | 598 | 132,032 | 198,048 |
| Taita Taveta | 331,170 | 10,929 | 1,093 | 153 | 71,689 | 71,689 |
| Tana River | 288,353 | 12,169 | 1,217 | 170 | 110,062 | 220,123 |
| Tharaka | 458,242 | 15,168 | 1,517 | 212 | 97,427 | 194,854 |
| Trans Nzoia | 1,155,734 | 50,852 | 5,085 | 712 | 207,099 | 276,132 |
| Turkana | 816,941 | 41,827 | 4,183 | 586 | 133,790 | 267,580 |
| Uasin Gishu | 1,223,866 | 51,892 | 5,189 | 726 | 144,895 | 173,874 |
| Vihiga | 753,500 | 27,804 | 2,780 | 389 | 341,239 | 341,239 |
| Wajir | 1,198,420 | 62,558 | 6,256 | 876 | 276,206 | 414,309 |
| West Pokot | 667,664 | 29,377 | 2,938 | 411 | 209,064 | 418,127 |
| **Total** | **49,362,058** | **2,123,469** | **212,347** | **29,729** | **129,778** | **166,776** |

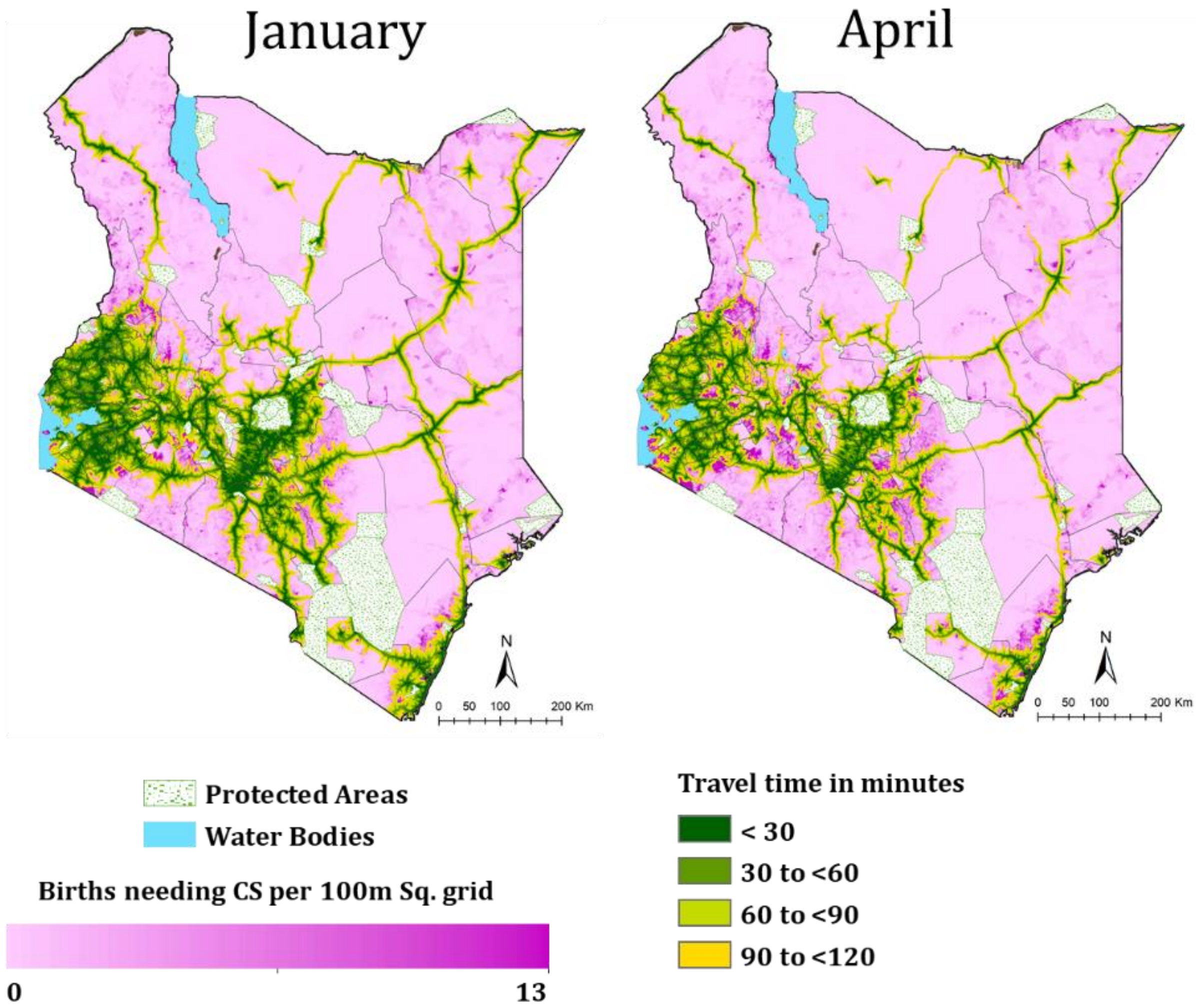
### 4.5.3 Geographic accessibility

#### 4.5.3.1 Access to Caesarean Section Hospitals

Nationally, the median population within 2 hours of a CS hospital was 82.24% [79.17% to 84.63%] in 2018. This translates to approximately 37,713 births requiring emergency CS living more than 2 hours from the nearest hospital. Population without access varied from 32,646 during the dry seasons to 44,223 during the wet seasons, highlighting the influence of seasonal variation on accessibility. Extensive marginalisation was observed in areas where populations were sparsely distributed, roads infrastructure were scarce and in poor condition or where few hospitals could perform caesarean deliveries such as areas in Northern Kenya. Unmet need for access to CS hospitals was highlighted as those with high density but are more than two hours from the nearest CS hospital (Figure 4.13).

Counties such as Turkana, Wajir, Mandera and Marsabit had significant swaths of populated areas that were more than 2 hours from the nearest CS hospital with poor access increasing from the dry to the wet seasons. Examples of the differences in access by month are shown in Figure 4.13. At county levels, accessibility quotients varied, with 30 counties having more than 80% of the population needing emergency CS being within 2 hours. In four of these counties (Kilifi, Kwale and Taita Taveta), however, accessibility was lower than 80% during the rainy seasons (Figure 4.14). Using the 1-hour threshold as a sensitivity analysis shows that the median access was 55.39% with county level variations as shown in Appendix 9. The lowest departure of the 1 hour access quotients from the 2 hour access quotients were observed in Garissa, Nairobi and Turkana. The highest differences were in Kwale and Nyandarua.

Figure 4.13 Variation in travel time to the nearest CS hospital showing Access to CS hospitals in January and in April. Dark green areas are those within 30 minutes with the lighter green areas having increased travel times. Population density is also shown in areas where travel time is more than 120 minutes, while water bodies and protected areas are masked out. The accessibility outputs for each month are shown in Appendix 7.




Proportion of population outside different travel time thresholds also varied nationally, mimicking a decay curve. Variation in access by season was highest at shorter travel time thresholds, reducing as travel time increased (Figure 4.15). For example, 64.5% were living outside 30 minutes varying from 58.8% to 67.2%, compared to those living outside 390 minutes who were 3.9% but varying from 3.4% to 5.3% between the wet and dry seasons.

Figure 4.14 Variation in access to both CS hospitals with medians shown as dots. The error bars are the uncertainty intervals because of variation in access by seasons. The horizontal red line is the 80% cutoff. The counties are ordered by the overall access quotients with red dots representing counties with access less than 80% and green dots the counties with access quotients more than 80%. The exact accessibility values are shown in Appendix 8.

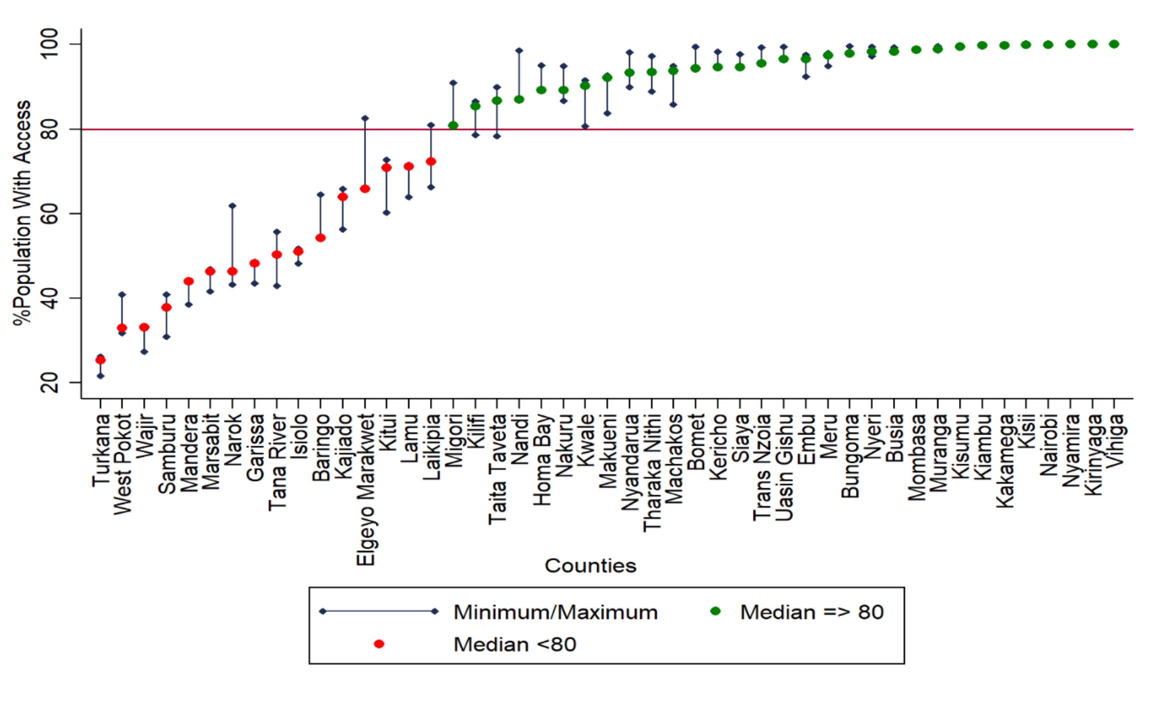
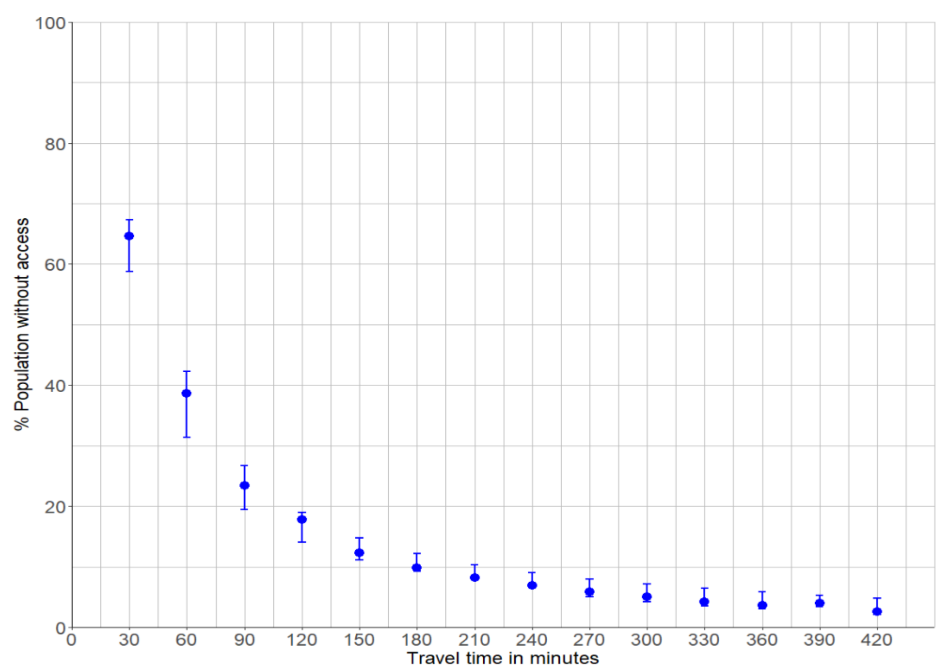



Figure 4.15 Distance decay showing proportion of population without access against different travel time thresholds nationally



#### 4.5.3.2 Access to VLBW hospitals

Nationally, 80.3% [78.0 to 83.4] of population in need of VLBW services were within 2 hours of the nearest VLBW hospital. Similar to the CS analysis, areas around Kenya were significantly underserved with a significant proportion of the population outside 2 hours. Accessibility reduced as rainfall estimates increased, getting poorest in the rainiest month of April (Figure 4.16). Overall, 17 counties had median access quotient less than 80%, while four counties with median access of more than 80%, did not reach this target across all the seasons (Figure 4.17).

Figure 4.16 Variation in travel time to the nearest VLBW hospital showing Access to VLBW hospitals in January and in April. Dark green areas are those within 30 minutes with the lighter green areas having increased travel times. Population density is also shown in areas where travel time is more than 120 minutes, while water bodies and protected areas are masked out.

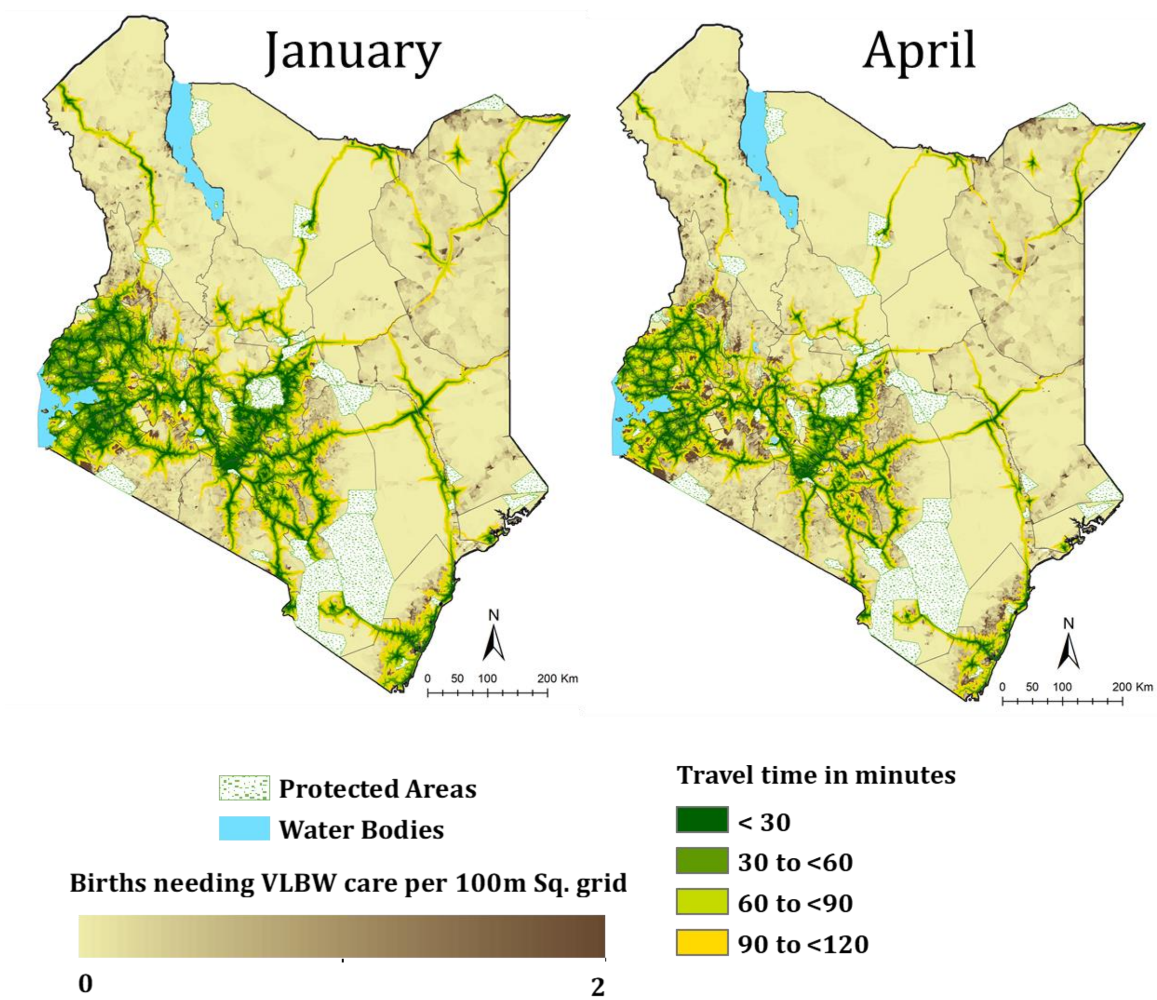
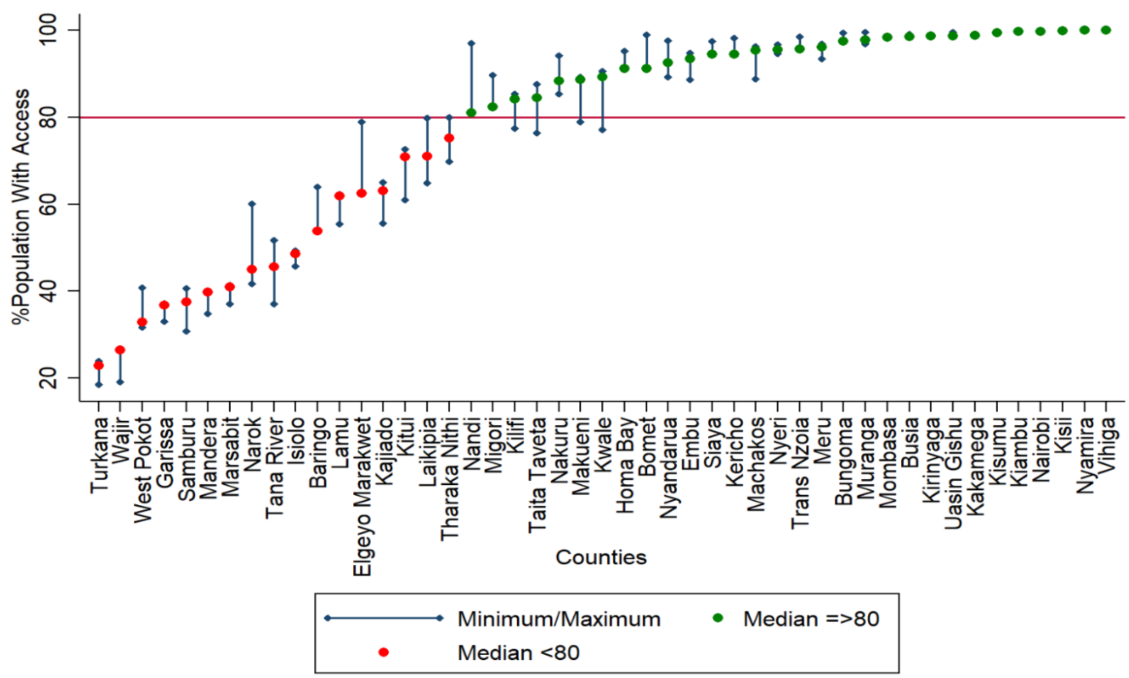
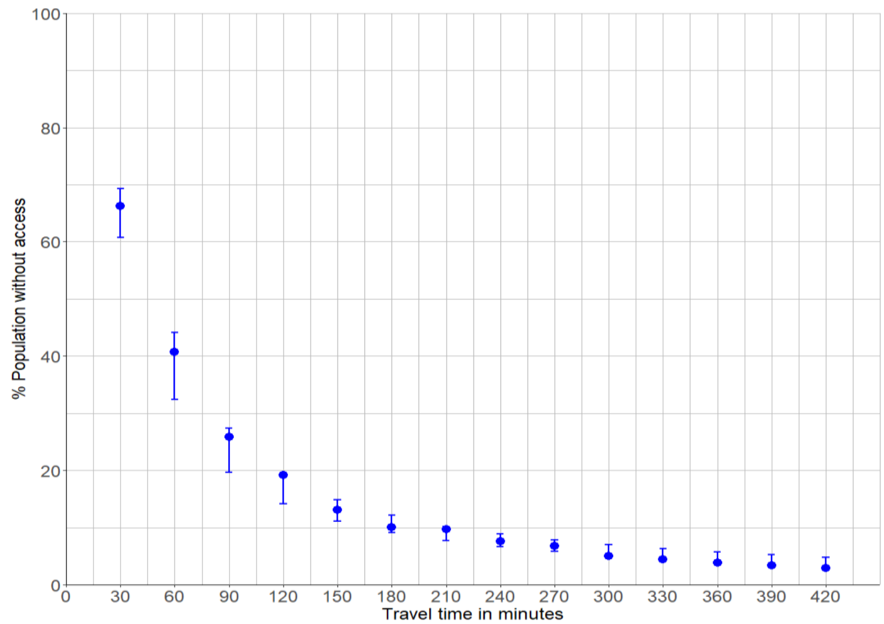


Figure 4.17 County-level variation in access to VLBW with the medians shown as dots. The error bars are the uncertainty intervals as a result of variation in access by seasons. The horizontal red line is the 80% cutoff. The counties are ordered by their overall access quotients, with counties having less than 80% access shown in red and those with more than median 80% in green. The exact accessibility values are shown in Appendix 8.




A distance decay phenomenon was observed, where accessibility reduced with decreasing travel times. At lower travel times, difference between the wet and dry seasons was higher, i.e. 60.7 to 66.2 using 30 minutes as threshold compared to 2.8 to 4.7 when using 420 minutes as a threshold (Figure 4.18). County-level access quotients are shown in Appendix 7. Counties such as Kakamega, Kiambu, Kisii, Muranga, Nairobi, Nyamira and Vihiga had almost all the population within 2 hours of the nearest VLBW facility. In counties such as Garissa, Isiolo, Mandera, Marsabit, Narok, Samburu, Turkana, Wajir and West Pokot had less than 50% of population within 2 hours. Using the 1-hour threshold as a sensitivity analysis shows that the median access was 50.27% [46.89 to 53.78], a 30% reduction from the 80.3% recorded in the 2-hour analysis. County level variations are shown in Appendix 9. The correlation between 2 hour and 1-hour access metrics was 0.93, with the greatest differences between the two time thresholds being highest in Embu, Kwale and Nyandarua with more than 60% access difference.

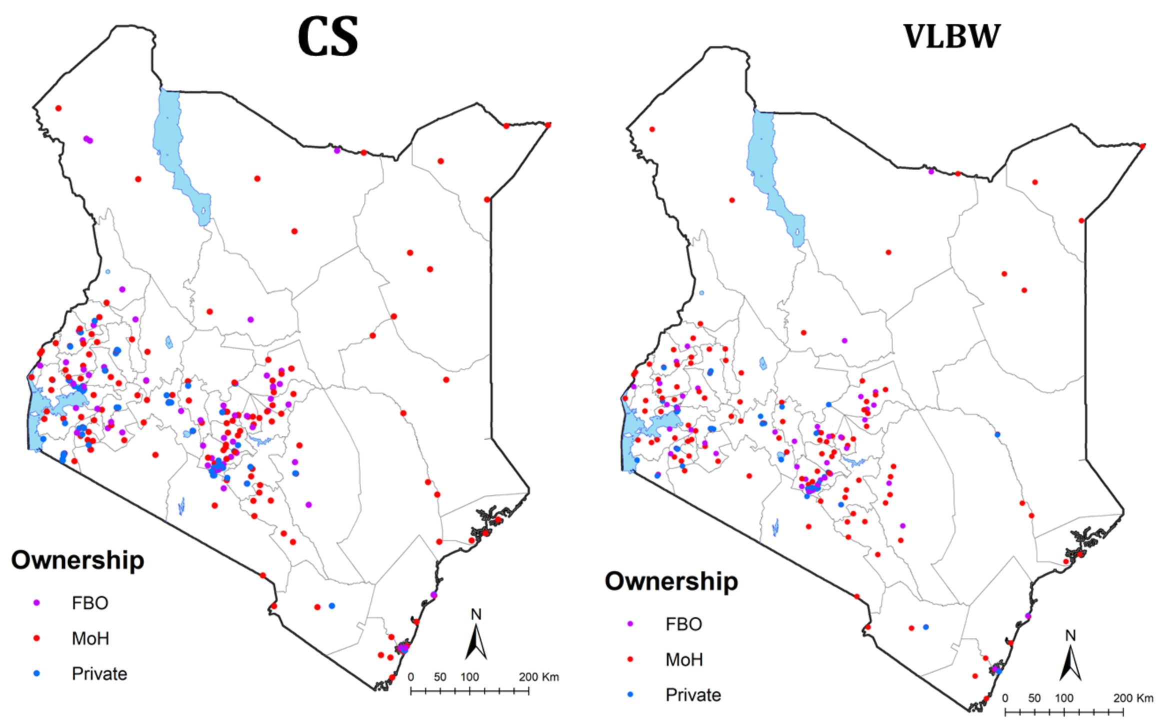
Figure 4.18 Distance decay showing the proportion of population without access to VLBW hospitals against different travel time thresholds nationally




### 4.5.3.3 The role of the private sector

The accessibility model was run for the public sector only, comprising of facilities owned by the MoH and the FBOs. Nationally, access to both CS and VLBW hospitals were not different; 82.03 for access to CS and 80.1 for access to VLBW hospitals. It is worth noting that the private sector facilities are mainly located in urban areas where there are existing public facilities (MoH, FBO or NGO not for profit) and therefore would not increase coverage of services as shown in Figure 4.19. Most private facilities were in densely populated counties like Nairobi, Mombasa and Kisumu.

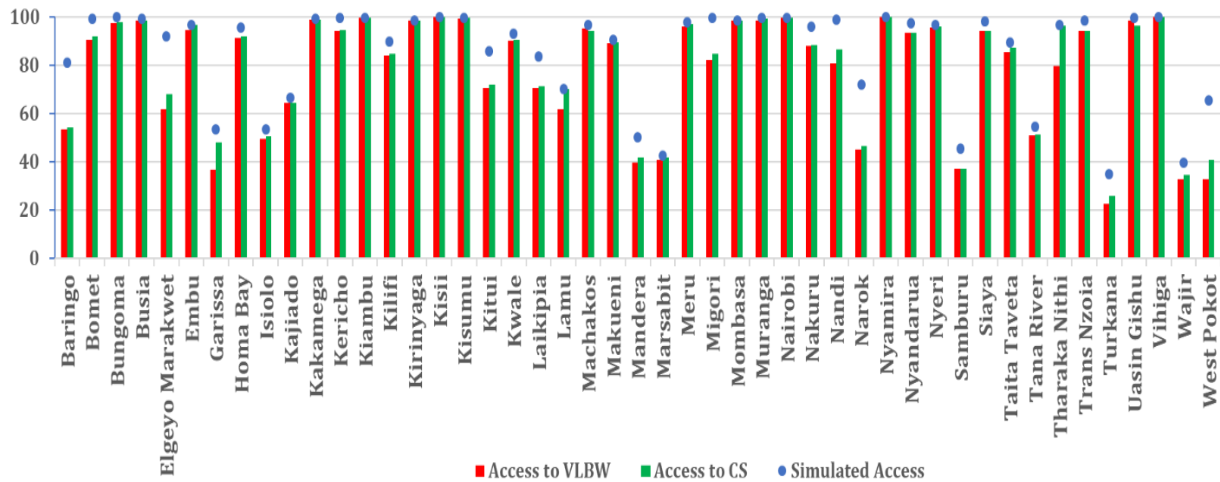
Figure 4.19 Distribution of CS and VLBW hospitals by ownership category.




#### 4.5.3.4 Simulated Access based on all hospitals

The accessibility model was also run for all the 431 hospitals that either provided CS or VLBW services in addition to including all the possible hospitals which could be providing CS and VLBW services. This was mainly to provide a what if scenario based on the possible strategy off upgrading each of these facilities to provide CEmONC services. Results show that 87.4% of the total populations would have access to these facilities, an increase from the 82.2% and 80.3% that have access to CS and VLBW facilities respectively. with 12 counties still falling below the access quotient of 80%. Accessibility would still be poor in counties such as Turkana, Wajir, Marsabit and Samburu where more than 50% of the population would still be more than 2 hours from the nearest hospital. Comparison of accessibility quotients from the simulated results to both CS and VLBW hospitals are shown in Figure 4.20.

Figure 4.20 Comparison between accessibility to CS, VLBW hospitals and the simulated results. The blue dots shows how accessibility metrics would be in the simulated scenario, while the bar graphs are for both access to CS and VLBW.




## 4.6 Discussion

This Chapter highlights the differences in access to CEmONC hospitals in Kenya. Using CS and care for newborns with VLBW as tracers for hospital service availability, it was determined that 293 and 228 hospitals have the necessary staffing, human resources and equipment necessary to offer the two services respectively. On the other hand, 201 hospitals provided both CS and VLBW services. The number of these hospitals was much lower than the 399 hospitals assembled in Chapter 2. Cost distance geographic access models estimated that one in five mothers and newborns who need these services live more than two hours from the nearest hospital. This translates to approximately 6,000 VLBWs and 38,000 women needing emergency CS being marginalised from the hospital services they need. Access varied between and within counties, and these results can be used to design strategies aimed at improving hospital care in Kenya. Such initiatives include improving the capability of hospitals to provide comprehensive obstetric and neonatal services, ensuring adequate pre-referral care or other multisectoral interventions such as improving road network in the country.

Two critical tracer indicators required for adequate provision of CEmONC services were used as exemplars to assess hospital capacity to provide these services. Unanimous availability of all the six indicators was only available in 201 confirmed hospitals. This comprised mainly the major referral hospitals and indicates the poor coverage of first level referral hospitals in Kenya. There were however an additional 92 and 27 facilities in the CS and VLBW analysis respectively that made the minimum criteria for provision of these individual services, emphasizing where quality of maternal and newborn critical care hospital services may be suboptimal. These two services are critical in the definition of hospitals and further improvements of services will be important if the country is to achieve the relevant maternal and newborn deaths reduction by 2020. Possible hospitals which have at least one indicator and a significant amount of admissions but do not meet the minimum criteria for provision of CS and VLBW services highlight where service availability assessments were likely to be inadequate or facilities that require upgrading to provide these key services.

This analysis highlights the poor quality of general hospital services in Kenya. For example, 353 facilities had an infant incubator but only 237 (67%) of these had chest X-ray services while 298 (84%) had oxygen. Oxygen, for example, is critical in managing LBW newborns who commonly present with conditions such as birth asphyxia [Aluvaala et al., 2015a], respiratory distress syndrome or transient tachypnoea [Ruggins, 1991]. These neonates are also prone to apnoea and hyperventilation because of premature respiratory drive. These are common causes of neonatal deaths in Kenya and ensuring quality services such as oxygen can avert a significant proportion of neonatal deaths. Thus, the fact that there were 116 hospitals which have an infant incubator but no oxygen, highlights a lack of preparedness of hospitals in the country to care for VLBW newborns. Similarly, 408 facilities had an operating theatre, but only 356 (87%) of these offered blood transfusion services and had two doctors, despite having both services being two major requirements for CEmONC service provision [WHO et al., 2009]. These deficiencies are likely to extend beyond CEmONC service provision to, for example, patients presenting with severe cases of trauma who have been shown to face an elevated risk of death if haemorrhage is not managed [Weeber et al., 2018]. Thus, understanding which services are available at the different hospitals can offer a useful starting point for defining where equipment, infrastructure and human resources should be improved. For example, the availability of an operating theatre in addition to blood transfusion services can be used to establish where adequate staffing necessary for the provision of all bellwether surgical procedures should be provided.

In estimating accessibility an improved population layer was modelled to that used in Chapter 2. Compared to Worldpop raster layers, this population layer is less influenced by covariates such as proximity to roads or health facilities but instead relied more on high-resolution input data from enumeration areas. Besides, no previous study has estimated the exact population in need of services such as CS or VLBW, and the methods used can be useful when prioritising where services should be expanded. As an example, those without access to hospital services were estimated.

A key goal for reducing maternal and neonatal mortality is ensuring CEmONC services are accessible within a two-hour window [WHO et al., 2009; Meara et al., 2015]. These were global recommendations, but none of the Kenyan policy documents specifically identified the two- hour travel time threshold as important in measuring geographic access, instead they only focused on the 5km/1-hour window for primary care (Table 4.3). Other countries such as Tanzania, Rwanda and Ethiopia have developed national surgical and obstetric plans that identify the need to ensure people live within 2 hours of the nearest surgical and obstetric facility (Section 1.7), and given the importance of this travel time in reducing maternal deaths, Kenya should embed such recommendations in the health sector plans for adequate monitoring.

At the national level, the overall goal of attaining 80% coverage within 2 hours was achieved, but disparities still exist at sub-national levels and when considering different time points. Counties such as Turkana, West Pokot, Wajir, Mandera and Marsabit, have less than 50% of their births occurring within 2 hours of the nearest CS and VLBW hospitals. These counties account for only 9% of the national livebirths, but the need for equity and leaving no one behind demands increased investments in these counties. This suggests that improving accessibility in the country requires concerted efforts that focus on not only improving services in probable hospitals but also expanding services to poorly served areas as shown by the simulated scenario for access using all hospitals which increased access to 87.4%. However, using the 1-hour threshold for sensitivity shows differences in access in the counties to the 2-hour metrics. In some counties such as Vihiga and Nairobi, the differences were less than 2% showing areas where coverage of hospitals is good.

Counties with poor accessibility also had wider variation in access quotients when adjusting for seasonality, suggesting that they not only have poor coverage of hospitals services but also have poor road networks that hamper year-round access. In addition, populations in these counties are sparsely distributed thus, introducing difficulties in making assumptions of transport availability. Thus, in these counties, expanding hospital services to where there is unmet need is critical and a starting point for this would be the possible hospitals. The simulated accessibility model using all the 431 hospitals (which includes all the possible hospitals) suggests that access would improve to 87% (Figure 4.20). Given that 13% would still be marginalized this suggests that improving hospital service availability may not be sufficient in improving access if this is not accompanied by interventions such as improving ambulatory care, road networks and implementing the concept of maternity waiting homes and this is an area that requires further interrogation such as was done in [Bailey et al., 2011]. For example, although access to CS hospitals is 80% improving the road network to provide year-round access can increase those within 2 hours to 83%.

Improving access should be aligned with improvement in the quality of existing services, effective strategies should include strengthening early recognition of danger signs at lower-level facilities, provision of maternity waiting homes, improving ambulatory care and improving road networks [WHO et al., 2009]. As a theoretical model of access is used, accessibility does not imply quality services are available - these will be discussed in detail in the limitations section – but rather counties with high access quotients should shift focus towards improving quality of care. Indeed, current estimates attribute 21-32% of all maternal and neonatal deaths to poor quality maternal and newborn care, and improving quality will be key to achieving the SDGs [Chou et al., 2019]. In counties with access quotients oscillating between more than 80% and less than 80% depending on the season, improving road network coverage will be one of the key interventions to consider. In short, providing temporal and spatial disaggregation of accessibility metrics offers an opportunity for identifying the most useful interventions, which is key in allocating ever limited resources in low- and middle-income countries.

The private sector remains critical in expanding access to CEmONC services in Kenya. 28% of CS and 25% of VLBW hospitals were private facilities, with numbers high in densely populated counties like Nairobi, Mombasa and Kisumu. Although the geographic accessibility metrics were not significantly different when private sector was excluded from the model, this was because private facilities are near other public sector hospitals. However, these facilities offer an alternative to the public while also expanding services in densely populated areas where facility to population ratios would otherwise be poor.

### 4.6.1 Limitations

This analysis had several limitations. First, in refining the definition of hospitals, secondary data was used where in some cases only availability was reported while unavailability not reported. Thus, it was not possible to distinguish between missing data or unavailability in all facilities and this could have an impact on the defined hospitals. Nonetheless, triangulation from different sources and data types was used to reduce the influence of this limitation. Second, hospital service availability may not translate to quality health care and this was demonstrated in an observational cohort study that reported maternal mortality following caesarean deliveries are 50 times higher than those in high-income countries. This was mainly driven by the inability to offer care in mothers with peripartum haemorrhage and anaesthesia complications [Bishop et al., 2019]. Third, some indicators such as staff availability may also be subject to variations from time to time and this may affect the selection of hospitals. Fourth, in the absence of community survey datasets on prevalence of VLBW, hospital-based datasets which only capture births occurring in hospitals were used. Only two DSS sources were found and there is need for more sources of data on birthweight at community levels. It was also not possible to account for elective CS that may overburden the health system. Alternatively, prospective DSS type studies of pregnancy would improve the estimation of prevalence of CS.

Fifth, geographic access model was limited to proximity and could not account for the capacity to handle these services. As such factors such as waiting times were not accounted for and in areas where populations in need are significantly higher compared to services available, access may be reduced. The model was also not able to account for various health system shocks such as disruption of access to care due to health worker strikes or epidemics. Lastly, accessibility may also be affected by a multitude of individual-level factors such as cost, transport availability, population movement and service acceptability or choice. Nonetheless, the results present a strong case for where patients might have trouble accessing services if they needed to.

### 4.6.2 Summary

Despite these limitations, the results provide significant improvement in the understanding of definition of hospitals in Kenya, using CS and VLBW care as examples. Several sources were used to assemble a list of hospitals capable of providing crucial maternal and newborn inpatient services providing a clear picture of service availability. In Chapter 2, the definition of a hospital did not include any service availability assessment and either missed out on facilities without the name hospitals but provide hospital services or was called hospitals but do not offer required services. In addition, an improved population surface that excludes covariates that may introduce circularity in the accessibility metrics, commonly used in the Worldpop iterations were also computed [Linard et al., 2012; Sorichetta et al., 2015]. These are major improvements to recent analyses of access to CS or surgical care in the country [Juran et al., 2018; Gage et al., 2019]. By extension, Gage *et al.* (2019) used their result of accessibility to provide a policy recommendation that Kenya should shift all deliveries to hospitals because almost every woman of childbearing age had access to these services. This was based on hospitals obtained from the master facility list without accounting for service availability and a geographic access model that could not account for the limitations such as seasonal variation and population estimates that introduce circularity. This Chapter, therefore, cautions against the adoption of such a recommendation given the results of poor access and indications of poor quality in several counties. The geographic accessibility model is also an improvement to the one used in Chapter 2 or recent analysis of access to surgical care [Tansley et al., 2015; Stewart et al., 2016]. For example, assessment of uncertainty had previously applied a 20% adjustment factor to original transport speeds, but this Chapter shows how empiric data on seasonality can be used to vary transport speeds. Thus, improved metrics of access were produced.

This study shows that only, 293 and 228 hospitals respectively have the necessary staffing, equipment and infrastructure required to provide these crucial inpatient services while only 201 hospitals have both services available. Using a geographic accessibility model that accounted for differences in land use factors affecting transportation, shows that 18% of births needing CS services and 20% of those needing VLBW services live more than 2 hours from the nearest hospital, with substantial variations at county levels. These differences were further amplified when the condition of roads and seasonality were considered, highlighting the need for multi-sectoral approaches if accessibility gaps to CEmONC services are to be reduced in the country. Poor access to CEmONC services is expected to exacerbate maternal and neonatal outcomes, but this relationship remains unexplored in the Kenyan context. Therefore, the next chapter explores the relationship between access to CS and VLBW services and maternal and neonatal mortality.

# Chapter 5: Relationship between access to CEMONC facilities and maternal and neonatal mortality in Kenya

## 5.1 Background

In Chapter 3, the relationship between geographic access and maternal and neonatal mortality was explored at a continental level, using country-level datasets. However, the main challenge was the use of generic term hospitals but for which specific service provision capacities were not ascertained when developing the access model in Chapter 2, and this could have potentially led to the insignificant relationship with neonatal mortality in Chapter 3. Chapter 4 addressed the major limitation in Chapter 2 by using Kenya as an example to define hospitals able to provide CEmONC services and subsequently use these in an improved accessibility model that defined geographic access to CEmONC in Kenya. This was done using two major tracer indicators, CS and care for VLBW, as a signal for providing CEmONC and results of access aggregated at county levels. As was shown in the results section of Chapter 4, there were significant variations in access and the reviews in Section 1.10.1 showed that counties with poorer access are expected to have poorer outcomes and vice versa.

This Chapter aimed to evaluate the relationship between access to CS and VLBW hospitals and maternal and neonatal mortality respectively using disaggregated data at county levels. This was done while controlling for other determinants of both maternal and neonatal mortality at county levels. The analysis was conducted using methods similar to the ones used in Chapter 3, where confounders were selected within the context of the conceptual frameworks in Section 1.6. The Chapter therefore provides a brief description of how variables were assembled, the procedure for assessing the relationship 5.2, results in Section 5.3, and a discussion of the implication of these results in Section 5.4.

## 5.2 Methods

### 5.2.1 Sources of maternal and neonatal mortality

Section 4.2.7 demonstrated the differences in maternal and neonatal mortality in Kenya at county levels that were primarily driven by differences in maternal and newborn care practices and interventions. Maternal and neonatal mortality estimates are available from different sources. The EQUIST tool mapped MMR and NMR for the year 2016, in a process that used several interventions to disaggregate mortality estimates at county levels. The 2009 census MMR presented the most comprehensive estimates of county level MMR to date, where sisterhood method was used to enumerate maternal deaths during the census. Similarly, modelled estimates of NMR were produced using 2014 DHS data without using any covariates, although the major limitation was the insufficient sampling frame [Paige et al., 2019]. In this Chapter, all the four outcomes were used in assessing the relationship between access to VLBW and CS hospitals against both neonatal and maternal mortality respectively.

### 5.2.2 Access to hospital care

Hospitals providing caesarean section and VLBW services were mapped as tracer services for the provision of higher-level inpatient maternal and newborn care respectively. Cost distance algorithms were then used to define geographic access to these hospitals, with the number of births living within two hours of either a CS or VLBW hospital being a measure of access (Chapter 4). The hypothesis was that counties with poor access metrics would have poorer outcomes. This hypothesis remains largely unexplored forming the main aim of this Chapter.

### 5.2.3 Selection of confounders

The analytical process was similar to the one used in Chapter 3. Rationale for the choice of each confounder was provided in Section 3.2.3. None of the covariates incorporated maternal education in the modelling and this allowed the use of education as a confounder. In both outcomes drawn from the EQUIST, interventions were used to provide county level estimates, and these were excluded from the relationship assessment. The confounders are summarised in Table 5.1.

Table 5.1 Confounding variables used in the relationship assessment.

| Group | Covariate (shortname) | Meaning |
|---|---|---|
| **Socio economic well being** | Wealth | The proportion of households classified as poor or poorer by wealth index |
| **Maternal Knowledge and autonomy** | Meducation | The proportion of mothers (15-49 years) who had less than primary education |
| **Fertility and birth practices** | Birth_Interval | length of time between births |
| | Parity | The proportion of women aged, <30 years with 3 or more children or aged >29 years with 5 or more children |
| | Adolescent_Fertility | Adolescent women age 15-19 are already mothers or pregnant with their first child |
| | Fertility_Rate | Births per woman |
| **Access to healthcare** | HWorkforce | Health workforce (nurses, clinical officers and doctors) density per 10,000 population |
| | Geographic access to hospitals | Proportion within 2 hours of the nearest hospital |

All the variables were estimated at county levels using a smoothed small area estimation (SAE) model as described in [Macharia et al., 2019]. In brief, the SAE model was used to provide estimates by allowing counties with poorly sampled data to borrow from those with more information. This was done using a Bayesian gaussian process regression model that accounted for the large sampling variance and heterogeneity while exploiting spatial relatedness. The model for each variable was run using an MCMC algorithm in the R (Version 3.4.1) using 10,000 posterior samples of smoothed estimates.

### 5.2.4 Summary of the analytical process

The analytical process followed the one described in Chapter 3. The first step involved assessment of bivariable (crude) relationships between access and both outcomes. Relationships with $p>0.20$ were excluded from the subsequent steps. Variables which were used in modelling MMR and NMR in the EQUIST model were excluded to avoid circularity (Table 5.2). In the next step, the regularization technique was used to perform variable selection, using the elastic net regression (Section 3.2.5). This process however excluded geographic access, maternal education, wealth and health workforce density which were automatically included in the multivariable model.

Geographic access was included because it is the primary variable of interest while the maternal education, wealth and health workforce were automatically included because of their importance in explaining maternal and newborn deaths (Table 1.8). The variables selected by the elastic net regression were the only ones included in the final multivariable models. The third step was to fit the multivariable regression models that define the relationship between access and mortality while adjusting for confounders. MMR was also obtained from 2009 census and the confounders were estimated from data in 2009. The 2009 MMR output was included because it captures a census of maternal deaths while also not using any covariates to provide county level estimates. However, one major limitation is that the access metric is representative of 2018.

Table 5.2 Variable select using different outcomes. Those that were used in the assessment are marked as Y in each column.

| Group | Covariate | CENSUS MMR (2009) | EQUIST MMR (2014) | EQUIST NMR (2014) | PAIGE NMR (2014) |
|---|---|---|---|---|---|
| Socio economic disadvantage | Wealth | Y | Y | Y | Y |
| Maternal Knowledge and autonomy | Meducation | Y | Y | Y | Y |
| Fertility and birth practices | Birth_Interval | Y | | | Y |
| | Parity | Y | | | Y |
| | Adolescent_Fertility | Y | Y | Y | Y |
| | Fertility_Rate | Y | | | Y |
| Access to healthcare | HWorkforce | Y | Y | Y | Y |
| | Geographic access to hospitals | Y | Y | Y | Y |
| Percentage of urban populations | Urbanization | Y | Y | Y | Y |

### 5.2.5 Bivariable relationships

The aim was to assess the unadjusted relationship between access to CS hospitals and MMR and access to VLBW hospitals and NMR. Because CS is also always done to reduce the risk to the baby, a sensitivity analysis was done by relating access to CS hospitals with NMR. In the first step, linear regression graphs were plotted for each variable visually to evaluate non-linearity. Because a visual inspection showed that some variables may have error distributions other than normal distribution, generalised linear models (GLMs) which are flexible generalizations of ordinary least squares linear regressions were fitted. In the bivariable models, the variables with p values lower than 0.20 were used in the subsequent steps.

### 5.2.6 Model selection using regularization technique

As was done in Chapter 3, geographic access to hospitals, health workforce, maternal education and wealth were included in the multivariable model a priori and thus not subjected to the regularization process. As described in Chapter 3, the elastic net regression technique, a form of regularization was used to identify variables (in addition to geographic access to hospitals, health workforce, maternal education and wealth) that would best explain the outcome while avoiding overfitting.

### 5.2.7 Fitting the multivariable model

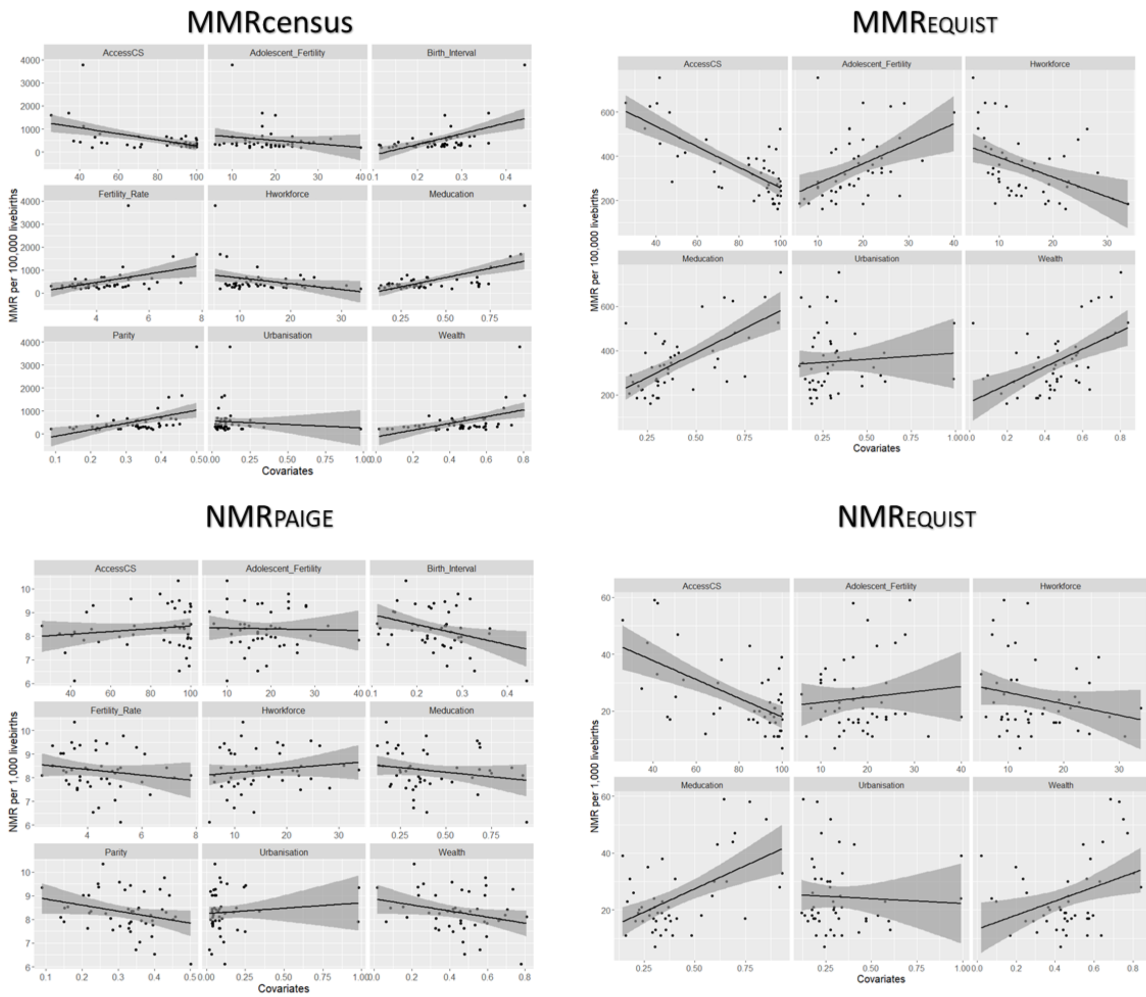
In the multivariable model selection, a generalised linear model was fitted using maternal education, wealth, travel time to facilities and health workforce density and those selected in the regularization technique. Additional variables selected from the elastic net regression were added to this model. Significance was interpreted as having $p<0.05$ and was only interpreted for the geographic accessibility variable. Sensitivity analyses, using access metrics in Appendix 9 were also conducted, by replacing the 2-hour travel time access metrics with the 1 hour access metrics.

## 5.3 Results

### 5.3.1 Bivariable relationships between access and outcomes

The crude (bivariate) analysis using linear models showed that accessibility was significantly associated with both MMR and NMR. Increasing proportion of population with access to CS hospitals was associated with reduction in MMR with a coefficient of -0.023 [95% CI -0.037 - 0.0137) using the $MMR_{census}$ and -0.012 [95% CI -0.015 to -0.009] using the $MMR_{EQUIST}$. Similarly, proximity to VLBW hospitals was associated with a reduction in $NMR_{EQUIST}$, with a coefficient of -0.012 [95% CI -0.017 to -0.008], but the association was not significant when using $NMR_{PAIGE}$, which had a coefficient of 0.001 [95% CI -0.001 to 0.002]. All other unadjusted relationships between access and both MMR and NMR are shown in Figure 5.1. These highlight nonlinear relationships for example between access to CS and MMR from the census, prompting the use of glms. Model parameters of the glms are shown in Table 5.3. Access to VLBW hospitals was not significantly associated with the NMR$_{PAIGE}$ as an outcome and NMR$_{PAIGE}$ was dropped in the subsequent analysis. Urbanisation was dropped in all the models because of the poor association with each outcome.

Figure 5.1 Unadjusted relationships between each variable and all the outcomes




**Footnote:** Wealth; The proportion of households classified as poor or poorer by wealth index, Meducation; The proportion of mothers (15-49 years) who had less than primary education, Birth_Interval; length of time between births, Parity; The proportion of women aged, <30 years with 3 or more children or aged >29 years with 5 or more children, Adolescent_Fertility; Adolescent women age 15-19 are already mothers or pregnant with their first child, Fertility_Rate; Births per woman, HWorkforce; Health workforce (nurses, clinical officers and doctors) density per 10,000 population, Geographic access to hospitals; Proportion within 2 hours of the nearest hospital.

Table 5.3 Unadjusted model parameters showing their respective coefficients, upper and lower bounds in brackets and p values. Variables which were not significant are shown with p values in bold.

| | MMR CENSUS | | MMR EQUIST | | NMR EQUIST | | NMR Paige | |
|---|---|---|---|---|---|---|---|---|
| **Variable** | **Coefficient** | **p Val** | **Coefficient** | **p Val** | **Coefficient** | **p Val** | **Coefficient** | **p Val** |
| Geographic Access | -0.023 [-0.036 to -0.013] | <0.0001 | -4.659 [-5.866 to -3.452] | <0.0001 | -0.330 [-0.459 to -0.201] | <0.0001 | 0.001 [-0.001 to 0.002] | **0.3670** |
| HWorkforce | -0.760 [0.000 to -0.318] | <0.0001 | -8.882 [-14.172 to -3.591] | 0.0019 | -0.401 [-0.910 to 0.107] | 0.129 | 0.002 [-0.002 to 0.006] | **0.3170** |
| Fertility Rate | 0.301 [0.111 to 0.492] | 0.0024 | | | | | -0.015 [-0.039 to 0.010] | **0.2520** |
| Adolescent Fertility | -0.030 [-0.089 to 0.016] | 0.1970 | 9.010 [3.673 to 14.347] | 0.0018 | 0.186 [-0.338 to 0.711] | **0.4890** | 0.000 [-0.005 to 0.004] | **0.8510** |
| Parity | 17.413 [12.813 to 22.939] | <0.0001 | | | | | -0.312 [-0.623 to -0.001] | 0.0553 |
| Wealth | 5.7373 [3.324 to 7.249] | <0.0001 | 401.090 [214.498 to 587.675] | <0.0001 | 24.813 [6.6771 to 42.948] | 0.0102 | -0.139 [-0.294 to 0.017] | 0.0863 |
| Birth_Interval | 11.891 [9.497 to 15.987] | <0.0001 | | | | | -0.480 [-1.014 to 0.046] | 0.0827 |
| Meducation | 4.2803 [3.166 to 5.571] | <0.0001 | 444.760 [294.989 to 594.530] | <0.0001 | 32.551 [17.769 to 47.331] | <0.0001 | -0.093 [-0.241 to 0.051] | **0.2170** |
| Urbanisation | 6.2359 [-3.1251 to 15.55] | **0.259** | 564.709 [-194.833 to 987.530 | **0.347** | 12.682 [-0.529 to 27.871] | **0.296** | 0.000 [-0.004 to 0.004] | **0.750** |

### 5.3.2 Model selection using regularization

As was done in Chapter 3, geographic access to hospitals, health workforce, maternal education and wealth were included in the multivariable model a priori. Thus, the aim of regularization was to select the other variables among the remaining four that would confound the relationship between access and outcome best. Using $MMR_{Census}$, all the remaining four variables were included in the elastic net regression. The association for $MMR_{Census}$ was done using confounders generated from the 2009 DHS. However, for both EQUIST MMR and NMR outcomes, only adolescent fertility remained, and this was automatically added in the prior model. Thus, only results of the regularization using $MMR_{Census}$ are shown in Table 5.4. The table does not include geographic access, wealth, health workforce and maternal education which were automatically included in the multivariable model. Thus $MMR_{Census}$ results show that only parity was dropped and other variables with coefficients retained.

Table 5.4 Variables selected using Elastic Net regression using $MMR_{Census}$. Those with coefficients displayed were the variables selected while those with dots were the ones dropped.

| **Variable** | **Coefficient** |
|---|---:|
| Intercept | -1.603 |
| Fertility_Rate | 0.267 |
| Adolescent_Fertility | -0.051 |
| Parity | . |
| Birth_Interval | 5.646 |

### 5.3.3 Multivariable adjusted models

When access was adjusted for all the relevant confounders in the $MMR_{Census}$ model, there was a two-fold increase in the coefficient to -11.917 [95% CI -21.331 to -2.503] relative to coefficient from the crude model. Thus, increasing the proportion of women of childbearing age living within 2 hours of a hospital by one percent was associated with a decline in MMR by approximately 11.917 per 100,000 livebirths (p=0.000). In the $MMR_{EQUIST}$ model, the coefficient reduced to -3.805 [-5.791 to -1.818], showing that proximity to CS hospitals is associated with reduction in MMR.

Table 5.5 Multivariable adjusted models of the relationship between access to CS and MMR

| **Variable** | **$MMR_{Census}$** | | **$MMR_{EQUIST}$** | |
|---|---|---|---|---|
| | **Coefficient [95% CI]** | **p value** | **Coefficient** | **p value** |
| Intercept | 1762.459 [191.415 to 3333.502] | 0.034 | 635.275 [347.560 to 922.989] | <0.0001 |
| Geographic access to hospitals | -11.917 [-21.331 to -2.503] | 0.018 | -3.805 [-5.791 to -1.818] | <0.0001 |
| Wealth | 155.250 [-1093.590 to 1404.089] | 0.809 | -242.213 [-515.392 to 30.966] | 0.089 |
| Hworkforce | -11.616 [-34.991 to 11.759] | 0.336 | -3.611 [-8.353 to 1.132] | 0.143 |
| Meducation | 746.052 [-294.497 to 1786.601] | 0.168 | 169.017 [-109.510 to 447.545] | 0.241 |
| Fertility_Rate | -158.474 [-393.801 to 76.852] | 0.195 | 6.332 [2.265 to 10.399] | 0.004 |
| Birth_Interval | 2684.898 [-9.419 to 5379.216] | 0.058 | | |
| Adolescent_Fertility | -24.572 [-44.953 to -4.190] | 0.023 | | |

The multivariable model using the $NMR_{EQUIST}$ outcome shows that access to VLBW hospitals was also significantly associated with neonatal mortality when adjusting for other confounders. A percent point increase in access to VLBW hospitals was associated with a reduction of NMR by -0.235 [95% CI -0.466 to -0.003] with the final multivariable model showing the coefficients shown in Table 5.6.

Table 5.6 Multivariable adjusted models of the relationship between access to VLBW and $NMR_{EQUIST}$

| Variable | $NMR_{EQUIST}$ | |
|---|---|---|
| | **Coefficient** | **p value** |
| Intercept | 42.139<br>[7.471 to 76.808] | 0.022 |
| Geographic access to hospitals | -0.235<br>[-0.466 to -0.003] | 0.050 |
| Wealth | -14.559<br>[-47.876 to 18.756] | 0.397 |
| Hworkforce | -0.066<br>[-0.648 to 0.516] | 0.824 |
| Meducation | 19.667<br>[-14.283 to 53.618] | 0.263 |
| Fertility_Rate | 0.020<br>[-0.474 to 0.514] | 0.937 |

The sensitivity analysis using 1-hour time threshold, geographic access to hospitals (VLBW) was only significantly associated with $NMR_{EQUIST}$, but not $MMR_{Census}$ and $MMR_{EQUIST}$. The model coefficients are shown in Appendix 10. Given the importance of CS on reducing neonatal deaths, the results of the multivariable model assessing the influence of access to CS on $NMR_{EQUIST}$ are also explored. The coefficient for geographic access to CS was -0.265 [95% CI -0.505 to -0.025, p= 0.036] further amplifying the importance of CS.

## 5.4 Discussion

This chapter found that increasing access to CEmONC is associated with reductions in maternal and neonatal mortality. Using MMR outcomes from census and EQUIST outputs, a one percent increase in access to CS hospitals was associated with a reduction of MMR by 11.92 and 3.81 deaths per 100,000 livebirths using the census and EQUIST MMR outputs respectively. Thus, using the census outcome as an example suggests that MMR in high burden counties of Mandera, Marsabit, Turkana and Wajir would reduce by 457, 452, 647 and 540 per 100,000 livebirths respectively by ensuring all their livebirths use hospitals within 2 hours. Similarly, a one percent increase in access to VLBW hospitals was associated with a reduction of 0.24 neonatal deaths per

1,000 livebirths. Thus, Samburu, Turkana and West Pokot counties with access to VLBW quotients of less than 40, can reduce their NMRs by approximately 12 deaths per 1,000 livebirths by ensuring all births are within two hours of a VLBW hospital, further pushing the country towards achieving 2030 goals of 12 NMR by ensuring adequate access to quality VLBW hospitals.

As shown in Section 4.2.7 most maternal and newborn deaths in Kenya are due to causes that require timely critical hospital care. The coefficients of access to CS were different using the two outcomes; -11.917 for $MMR_{census}$ and -3.805 for $MMR_{EQUIST}$ and this could be attributed to two factors. First is that the outcomes are obtained from different sources, and while the $MMR_{census}$ was in theory a census of all maternal deaths and devoid of any covariates in modelling, the $MMR_{EQUIST}$ was a modelled output, where interventions were used to disaggregate outcomes at county levels. This potentially introduced some circularity in the estimates. Second is that both were representing different timepoints (seven-year difference) and the fact that the influence of access was smaller in the more recent EQUIST model suggests that proximity to CS services could have improved over the period, meaning that other factors such as quality of care could be becoming significant drivers. This could also explain the differences in coefficients. Nonetheless, both results show that improving geographic access to hospitals is associated with a reduction in MMR, consistent with results from Tanzania, where MMR due to direct causes increased from 111 to 422 with increase of distance to hospitals by 30 km [Hanson et al., 2015].

Similarly, proximity to VLBW hospitals was significantly associated with reduction in $NMR_{EQUIST}$ in both the crude and adjusted models. However, no association was observed when $NMR_{PAIGE}$ was used in the crude regression models. The unexpected lack of a significant relationship could be attributed to insufficient input data given that only a subset of newborn death occurring in the year 2014 was used. The lack of an association is however not unique, and has been observed in

Malawi, in a study that used distance to all facilities and early neonatal mortality for comparison [Lohela et al., 2012]. The main reasons for lack of an association may be similar, where obtaining neonatal deaths that are due to complications requiring hospital care are difficult to capture. Another reason could be that in areas with low skilled birth attendance use, the less use of maternal and newborn services means that cases are more likely to progress to complications, and they therefore use hospital services more frequently. This phenomena has been observed in Malawi and Bangladesh, where proportion of early neonatal deaths in hospitals have been seen to be higher than those occurring at home [Ronsmans et al., 2010; Lohela et al., 2012].

Nonetheless, the use of the modelled EQUIST output as the outcome shows the significance of improving access to VLBW hospitals. As interventions such as SBA and ANC were important in modelling the outcomes, improving access to hospitals should also be accompanied by improvement in these interventions. Finally, the role of reducing financial barriers towards accessing services is also important [Kukla et al., 2017; Salari et al., 2019], in addition to having adequate distribution of health workers. Other factors of importance include cultural and gender inequity barriers which can impede access to quality hospitals services and need to be addressed if the country is to achieve the 2030 goals of maternal and neonatal mortality.

The two-hour threshold which is recommended for defining access to CEmONC services was used to extract the subset of population in need that is marginalised. The two hour window is based on observed elevated maternal deaths from postpartum haemorrhage, if services are not available within this time window [WHO et al., 2009]. However, services may require a shorter time window and a sensitivity analysis was therefore done using the 1-hour travel time threshold instead of the two-hour threshold. However, this relationship was not visible when using MMR as an outcome highlighting the importance of the 2-hour window over the one-hour window in capturing those at risk. The one-hour threshold captured only those very close to urban areas, thus excluding those in rural areas. However, this relationship was still significant when using $NMR_{EQUIST}$ as the outcome, but the coefficient was smaller compared to the one observed using the 2-hour threshold. Thus, both sets of analysis support the use of 2-hour travel time window to define geographic access of CEmONC hospitals.

In Chapter 4, an alternative hypothetical scenario using all 431 hospitals that includes the possible hospitals was also produced. Possible hospitals were those that did not meet the criteria for VLBW and CS service provision but could be upgraded by including a few additional services. This mainly provided a case for where hospital services can be improved with an average quotient of 87% access achieved in the counties. In the initial access model, 16 counties had access quotients of less than this 87% threshold. Using the regression coefficients in this Chapter and assuming all confounders remain constant, then improving capacity of these hospitals to provide CS and VLBW services would mean $MMR_{Census}$ is reduced by an average of 363 these 16 counties. Similarly, NMR would reduce by an average of 6 in counties with access quotients less than 87%. This highlights the importance of improving service for maternal and newborn health.

Estimates of national and subnational burden of disease are often produced by the WHO and GBD. For example, attainment of SDG3 is being frequently updated by the GBD, using metrics that incorporate various indicators of service coverage [Barber et al., 2017; Hogan et al., 2018]. However, none has included a component of distance to facilities or hospitals, with distance to cities often used as a proxy for geographic access to health services. This Chapter shows that analysis of access to health services is important in defining inequities at both national and subnational levels, further providing a clearer picture for attainment of UHC. In addition, the outputs can be used to estimate burden of diseases, where areas further away from CEmONC hospitals are likely to have elevated risks or maternal and newborn deaths.

### 5.4.1 Limitations

This study had several limitations. First it was not possible to obtain temporally matched datasets for all the covariates and outcomes and this could have significantly affected the observed associations. Secondly, aggregation of outcomes to county levels masks heterogeneities that exist at individual levels. For example, counties in northern Kenya are all categorised to have poor interventions including geographic access even though there are some rural areas which would have relatively good access to interventions. Thirdly, poor quality of care in CEmONC hospitals may have overridden the influence of geographic access to these services hence also affecting the observed relationship. Fourth, is the limitations of the outputs in Chapter 4 would ostensibly affect analysis in this Chapter. These include assumption that quality services are provided and limitations of the access model such as inability to account for waiting times. Finally, it was not possible to separate maternal and neonatal deaths that may not require hospital services from the overall outcomes for better relationship assessment. This, however, requires up to date and accurate data on cause of death, which is difficult to obtain in many African countries.

### 5.4.2 Summary

Despite these limitations, this analysis provides important insight into the need for improving access to CEmONC services in Kenya. Counties need to prioritise improvement of hospital services as poor access to CS and VLBW hospitals was significantly associated with increasing maternal and neonatal mortality. However, there are still significant limitations in such analyses mainly regarding data availability and these have to be addressed in future studies to produced more nuanced results. The next Chapter will discuss all the findings in the four results Chapters (2-5), including what the results mean, how the results can be used, overall limitations and potential recommendations for improving future studies.

# Chapter 6: Discussion

## 6.1 Background

Ensuring timely access to hospital care is a critical component for achieving UHC [Ensor & Cooper, 2004], which is one of the key targets of SDG3 [UN, 2016]. While studies have shown the importance of access in achieving UHC, distance to hospitals remains inadequately interrogated in many LMICs, most of which are in SSA (Section 1.7.4). This is attributed to lack of health facility databases, in addition to inadequate data on the services provided in hospitals. Without an understanding of hospital locations and services, it remains difficult to define those who are marginalised and the impact this has on mortality.

This thesis set out to assemble hospital databases, develop geographic accessibility metrics for hospital care and relate these metrics to maternal and neonatal mortality. This was undertaken at the regional level in SSA and at a more refined national level in Kenya. For maternal and neonatal mortality access to CEmONC hospital services was deemed a good exemplar of broader hospital care. Most deaths during pregnancy, post-partum and during the neonatal period can be prevented if quality CEmONC services are available promptly (Section 1.5). Thus, understanding the subset of populations living far away from hospital services is critical in identifying where interventions need to be strengthened if the SDG targets of achieving global MMR of 70 per 100,000 livebirths and NMR of 12 per 1,000 livebirths by 2030 are to be achieved [UN, 2016].

It was hypothesised that having good access to CEmONC services can reduce risk of maternal and newborn deaths. As shown in the reviews in Section 1.9.1, timely access to hospitals is important if preventable maternal and newborn deaths are to be reduced [Table 1.9 and Figure 1.3]. Although distance is important in defining those at risk of not receiving timely care, few studies have investigated how geographic access relates to mortality. In addition, living within 2 hours of a CEmONC hospital is a useful measure of proximity mainly because of considerably high maternal deaths from postpartum haemorrhage, if services are not available within the two-hour time window [WHO et al., 2009]. However, the exact association between this accessibility metric with both maternal and neonatal mortality has been poorly studied (Section 1.9.1).

## 6.2 Summary of previous Chapters

Chapter 1 presented a review of previous methods that have been used to define access to CEmONC services, identified gaps and provided a justification for this work. This entailed a review of cornerstone HSSPs that describe services expected to be provided in hospitals, and this was used in justifying the use of hospitals as the health system entry point for providing CEmONC (Table 1.11). Gaps in previous methods including in parameterization of accessibility models were also identified, with the aim of addressing shortcomings such as assumptions on travel speeds, transport availability and overall handling of neighbourhood structure for the thesis.

In Chapter 2, the first spatial inventory of public hospitals in 48 SSA countries is presented. Here, public hospitals were defined as those that are managed by the MoH, not for profit NGOs and FBOs. Other datasets that were assembled were major roads that would theoretically support year-round motorised transport and the total number of women of childbearing age at 100m square grids. The assumptions of transport availability and use of motorised transport was based on the review of transport modes to hospitals in Section 1.9. A cost distance algorithm implemented using the AccessMod software was used to analyse geographic access to public hospitals. The model assumed a composite model of walking and motorised transport where patients would first walk to the nearest road from where motorised transport would be obtained. Access was defined as the population living within 2 hours of the nearest hospital and national quotients extracted.

With the evident disparities in access observed in Chapter 2, Chapter 3 hypothesised that differences in access would manifest in different outcomes. Using both MMR and NMR as outcomes, regression analysis found that after controlling for other confounders, a percent point increase in population living within 2 hours resulted in a significant decreased MMR by 2.73 per 100,000 livebirths ($p=0.038$) between countries, but the relationship was not significant when using NMR as the outcome.

The accessibility model in Chapter 4 was also a significant improvement from the one in Chapter 2, mainly because the model accounted for seasonality, details in roads were obtained from ministry of transport and an appropriate neighbourhood structure was used. In addition, travel speeds were assigned using data observed from the ministry of transport. The impact of these changes in addition to the service availability was manifested in the accessibility metrics being much lower for Kenya (82.2% for CS and 80.0% for VLBW) in comparison to the 92% reported in Chapter 2. If this difference is extrapolated to the different countries, then only 60% of WoCBA in the SSA countries analysed in Chapter 2 would be living within 2 hours of a hospital providing both CS and VLBW services. If additional quality of care metrics are added, then access quotients would be much lower.

The use of an improved model allowed for re-assessment of the relationship between access and both MMR and NMR, using data from county levels in Kenya. This was undertaken in Chapter 5, where different sources of MMR and NMR were used to assess their association with geographic accessibility. The two sources of MMR found coefficients of access that are significantly higher than those reported in Chapter 2 further emphasizing the importance of capturing physical barriers of access. NMR, on the other hand, was significantly associated with access, only when using a modelled output from EQUIST model. However, the census results, although the most comprehensive to-date were still very much outdated, and covariates had to be matched to those in the same period. The next sections therefore discuss the implications of these results.

## 6.3 Mapping hospital service provision in Africa

The pan-African hospital inventory mainly drawn from international organisations such as OCHA, UNICEF and WHO, with only few countries like Kenya, South Africa and Nigeria having complete master facility lists that were publicly available. This highlights the need for more countries to develop and routinely update their master facility lists and make them publicly available. At the very least, a health facility database should be accompanied by the relevant location attributes including coordinates and administrative units where they are located [WHO, 2013; USAID & WHO, 2018]. However, more than half of the sources did not have coordinates even in countries like Kenya with robust MFLs. Although other online tools such as like Google Maps and OpenStreetMaps can be used and are useful, the fidelity of such location data is only dependent on how good crowd sourcing is and lower level facilities may be missed or would take time before newer facilities are updated. There is therefore a need to ensure that facilities are mapped using the gold standard GPS method. The methods used in assembling the pan African hospital database have since been extended to all public facilities and this should form as a useful basis for countries to have a comprehensive geocoded inventory of all facilities [Maina et al., 2019].

Tied to mapping facilities is the need to define actual services provided in health facilities. The review of the minimum essential hospital services demonstrated the importance of hospitals in achieving UHC. However, there were ambiguities in definition of hospitals in SSA given the different services recommended in each country and this was evident in the inability to adequately tie the number of hospitals across different sources (Table 2.3). Thus, more refined definitions of what hospitals are needed and this at the very least requires a list of minimum essential services, equipment and personnel to establish hospital definition criteria, accompanied by regular service availability assessments to determine the facilities meeting the set-out criteria for definition of hospitals. Recommendations for minimum essential services already exist from different studies as shown in Table 6.1 and a selection of commonly used indicators can be useful.

Table 6.1 Typical definitions of primary hospitals based on the number of beds, admissions, equipment and personnel

| **Source** | **Beds** | **Annual Number of admissions** | **Equipment** | **Personnel** |
|---|---|---|---|---|
| [van Lerberghe & Lafort, 1990] | >140 | 4000 | Theatre, Blood transfusion, Anesthesia, X-Ray, Oxygen, Laboratory examinations, Gastroscopic, echographic equip, Dentistry equipment | Medical Officers, Specialists, BSN nurses |
| [Hamel & Janssen, 1988] | >140 | 5000 | Theatre, Laboratory services | Medical officers |
| [McCord et al., 2015] | >50 | | Anaesthetic machines, Theatre, Blood transfusion equipment, Respirators and oxygen supplies | Medical officers, Specialists, BSN nurses |
| [English et al., 2006] | > 80 | | Theatre, laboratory services, Equipment for chronic care | Specialists, Medical officers |
| [WHO, 2009] | > 100 | | Oxygen concentrators, Theatre, Blood transfusion services, Adult and pediatric resuscitator sets, Automatic non-invasive blood pressure monitor, vaporiser (s), Pulse oximeter, spare probes, Adult and pediatric*, Nerve stimulator, Electrocardiograph monitor | |
| [MoH, 2017] | > 150 | | Theatre, Radiology and imaging services, Specialized therapy services, General equipment- Defibrillator, ventilator, incubators. | Specialists, Medical officers |

Nonetheless, the hospital database was used to demonstrate marginalisation to hospital services, where eight countries were observed to have less than 50% of WoCBA within 2 hours. Countries with poor access metrics such as South Sudan, Mauritania, Eritrea, Niger, Sudan, Madagascar, Chad and Central African Republic can leverage on this information to target improvement strategies. For example, where population density was high but access to facilities poor and can be areas which would benefit from a new hospital. On the other hand, there can be areas with high population density and have a hospital nearby, but the facility lacks adequate equipment and human resource to provide essential hospital services, thus emphasizing the importance of determining services in hospitals. In addition to defining access to emergency hospital services, the generated publicly available hospital database has been used to define marginalisation to other services in the continent such as surgery [Juran et al., 2018] and to treatment centres for elderly patients of the Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [Geldsetzer et al., 2020].

The generated metrics of accessibility can be used as a component for tracking progress towards achieving UHC. As was shown in Section 1.4, metrics of UHC are often generated using a broad range of factors such as disease prevalence and use of interventions but often lack health system components such as proximity to services [WHO & The World Bank, 2017b]. Metrics of UHC have also been produced for access to surgical care, with one study using proportion of serious injuries transported by an ambulance as a proxy for geographic access to surgical care. Given the importance of hospitals as first point of providing essential surgical procedures [Table 1.11], the results can be used to define those who may be delayed from receiving adequate surgical care. However, an interrogation of services these hospitals provide is critical.

To demonstrate the importance of service availability assessments, Chapter 4 aimed to assemble facilities providing CS and VLBW services. A disparate list of data on service availability surveys and routinely collected data from DHIS2 was used to map facilities that provide CEmONC services in Kenya. Although the datasets were representative of different time points, a rigorous process of checking and merging was undertaken to develop a single inventory of CEmONC facilities in Kenya. This process needs to be embedded in the current HIS system or procedures for accreditation of facilities before inclusion in MFLs. This process was a major improvement from the results of Chapter 2, where 399 hospitals in Kenya were mapped and assumed to provide this crucial service. In addition, coverage of the private sector – which was not assessed in Chapter 2 - and is also key in extending access to services was also audited.

## 6.4 Marginalization to hospital services in Kenya

In defining CEmONC hospitals, ability to provide CS (including blood transfusion) and VLBW services were used as tracers. CS and blood transfusion are the two key signal functions for CEmONC (Section 4.3). These facilities should also provide the other BEmONC services (Table 1.5) but this information was not available for all facilities. VLBW was also included as a proxy for provision of critical hospital neonatal care in Kenya, because it requires a range of services including neonatal resuscitation, provision of warmth in addition to monitoring by medical officers to effectively care for such newborns. There is a high risk of neonatal deaths in absence of adequate care for VLBW newborns (Section 4.3.2). However, facilities with these two tracer conditions may still miss other BEmONC services. As was shown in Table 1.5 and Table 4.2, a broader range of services such as removal of retained products, administration of uterotoric drugs and provision of anticonvulsants is needed for the management of all maternal complications [WHO et al., 2009; MoH, 2011]. Newborns admitted to hospitals also require other services like CPAP and surfactant in case they have respiratory distress (Table 1.7) and using only the services for the provision of VLBW may be limiting. Other factors including water and sanitation, electricity, poor patient to population ratios among other indicators may also hamper provision of quality care. Thus, despite facilities meeting criteria for provision of the tracer conditions, quality or care may still have been poor. However, the two services were only used as tracer indicators and it is likely that those meeting the criteria provide other range of inpatient newborn and maternal services.

In total, 293 hospitals could provide CS services while a total of 201 providing both VLBW and CS services out of a total of 431 hospitals. This situation is likely to be reflected in other SSA countries, and inadequacy in the provision of CEmONC has been reported in other studies [Compaoré et al., 2014; Cavallaro et al., 2020]. The SARAM surveys have been conducted in 11 countries in SSA while there is significant coverage of DHIS2 in Africa, and these countries can be used as a starting point for further interrogation of hospital services

Estimates of accessibility were produced for the 47 counties of Kenya to provide a more refined metric of marginalization to CEmONC. While the country achieved the overall target of having more than 80% of the population within 2 hours, there are still counties that are lagging and to ensure no one is left behind, there is need to ensure these counties have adequate geographic access. In areas within 2 hours and with high population density may also have hospitals that lack the necessary equipment for the provision of emergency care for various other conditions, in which case priority should be in improving their capacities. Uncertainty in geographic access was also assessed in a different way from the methods used in Chapter 2. While Chapter 2 did this by adjusting original transport speeds by ± 20%, this Chapter used a combination of road conditions and weather patterns to model uncertainty.

There are several policy implications from these studies. Bridging the geographic accessibility gaps requires the implementation of various short- and long-term interventions. While increasing the number of hospitals may be ideal, this might pose a significant challenge in resource-constrained settings where it would take many years to ramp up enough fully functional hospitals needed to deliver services. Short and medium-term measures can, therefore, be adopted to reduce time to accessing interventions, and these include improving pre-referral care including access to ambulances, access to maternity waiting homes [Bailey et al., 2011], promotion of better detection of emergency conditions at lower-level facilities that are linked to hospitals and other multi-sectoral interventions like improving the road network infrastructure [Campbell et al., 2016]. Of interest will be ensuring universal coverage of recommended ANC visits. LMICs have been shown to have ANC4 coverage of between 10% and 50% which is lower than any other countries [Benova et al., 2018]. Quality ANC attendance reduces pregnancy related maternal and newborn complications and deaths and is also important in identifying women at risk of developing complications during labour. It is the initial link between the woman, her family and the health system and is therefore critical in increasing skilled birth attendance including CEmONC [Campbell et al., 2016]. Thus, efforts to increase coverage, capacity and quality of CEmONC should be accompanied by adequate improvement in quality ANC attendance.

In addition to improving ANC coverage and access to services including workforce there is also need to ensure financial protection from impoverishing expenditures. As was described in Section 4.2.5, Kenya has over the years made significant strides in trying to close the gap in achieving financial protection, including the latest *linda mama boresha jamii* initiative that essentially removed all the direct medical costs for maternal services. However, implementation of this policy may still face challenges mainly form high non-medical costs, especially due to transportation [Salari et al., 2019]. Mothers living further away from CEmONC hospitals may have to pay more than those living closer to these facilities, essentially widening the equity gap.

Thus, financial protection policies that consider geographic marginalization are needed to ensure the initiative is fully implemented.

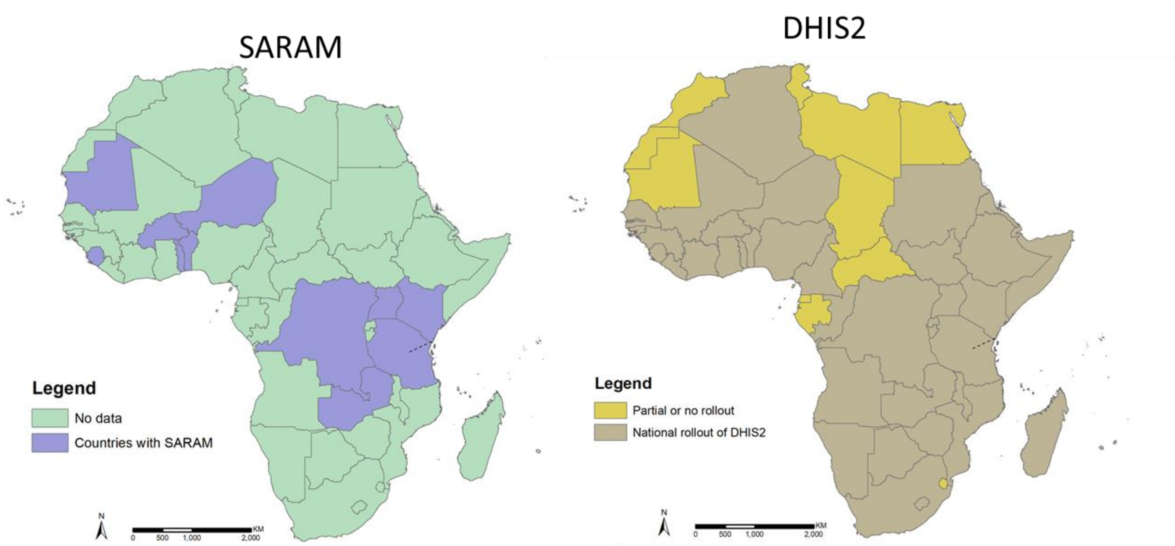
In Kenya, the health system is devolved, with the bulk of health decision making done at county levels (Section 4.2.2). The counties can, therefore, leverage the information on service availability and the accessibility outputs to develop strategies for improving accessibility. Maternal and newborn health is reliant on adequate referral care, where mothers often present to the nearest lower-level facilities and in case complications are developed by the mother or the baby transferred to EmONC facilities. This requires adequate planning and linkage between facilities for a timely referral. Accessibility results at county levels can, therefore, be critical baseline information for development of GIS referral zones as is required in the MoH referral strategy [Ministry of Health, 2014]. To date, referral zones for hospitals have not been developed and this is an area that will require further attention, especially with availability of the accessibility results and recently published health facility databases [Maina et al., 2019].

Despite the efforts to capture most physical aspects of geographic accessibility, it was still not possible within the scope of this work to account for factors such urban traffic snarl-ups, transport availability and accurate variation in travel speeds. In addition, the 2-hour travel metric was used to define accessibility. This travel time threshold has been proposed based on observed risk of mortality due to post-partum haemorrhage in the absence of adequate care. However, some causes of death may require shorter or longer time to prevent death from occurring. The use of 1 hour for sensitivity analysis shows that some counties had lower access quotients with significant differences observed in counties that had poor metrics in the 2-hour model. This could point to accessibility being poorer than is represented in the 2-hour scenario, especially if the additional 1 hour is assumed to be taken up by time to decision to seek care, transportation waiting times and/or waiting times once at the facilities. Although the review in Section 1.9 defined transportation pathways to hospitals, treatment seeking varies significantly across Africa. Thus, more small-scale studies that account for patient level treatment seeking pathways are needed. An example is a recent study which used travel time data that accounts for urban traffic information from google maps to define geographic access to trauma care in Nairobi [Shaw et al., 2017]. Assessment of uncertainty can also be improved with additional data on travel speeds and waiting times.

## 6.5 Implications of the Kenya results to other LMICs

The methodology used in Kenya can be extended to the other countries with available data (Figure 6.1). Coverage of SPAs which also show readiness to provide hospital services is however not highlighted as these do not provide facility level outputs.

Figure 6.1 Countries with SARAM surveys and those with DHIS2




Despite the SARA survey being the main tool for assessment of service availability, the fact that Chapter 4 had to rely on additional resources beyond the SARA/HHFA to provide a comprehensive picture is a concern, and effort should be put in improving the data collection methods or the sampling frame. Besides, these datasets were not publicly available, and all actors involved in data collection such as ministries of health and international partners need to ensure availability of these datasets for improved use. Finally, monitoring of services such as oxygen and health workforce needs to be a continuous process that can only be captured using routine data collection platforms such as DHIS2 that capture real-time variations.

Even though CEmONC was used as an exemplar, the situation is likely to extend to other hospital services such as surgery and paediatric care. Such deficiencies in hospital service provision have been reported in studies mapping access to surgical care in different countries of SSA [Esquivel et al., 2016; Stewart et al., 2016; Knowlton et al., 2017b]. Thus, the methods used in defining hospitals in Kenya can be extended to the assessment of other hospital level services. At the very least, the 201 confirmed hospitals can be used as a baseline for defining which facilities are hospitals in the country. Very few LMICs have hospital databases in addition to the services they provide and this hamper planning for critical care service provision. This is particularly worrying given the significant burden of road traffic accidents, and the rising number of cardiovascular diseases and cancers all which may require critical care [Gouda et al., 2019], and this may be a significant impediment towards achieving UHC in many LMICs.

Emerging epidemic threats such as Ebola virus disease, Middle East respiratory syndrome coronavirus, and yellow fever are occurring at increased scales, in most cases with damaging consequences in the absence of adequate hospital care [Lee et al., 2020]. For example, the transmission of SARS-CoV-2 since December 2019, has left many LMICs exposed, and with most of these countries not having an accurate picture of oxygen and intensive care capacity, adequate planning for a surge in cases is significantly hindered. Hospitals have also been used as sentinel sites for monitoring of intervention use and outcomes [Ayieko et al., 2016; English et al., 2018], and understanding their distribution is important. The defined hospitals with beds and oxygen capacity have been used to define the capacity of the existing health system in Kenya to manage a surge in SARS-CoV-2 cases and could possibly be extended to countries in Figure 6.1 and other LMICs with similar data [Barasa et al., 2020].

## 6.6 Understanding the relationship between access and maternal and newborn mortality

The relationship between access and maternal mortality was significant at both continental and a national scale. However, at a continental scale, access to hospital care was not as significant as it was in the national level analysis. The implications of these results were discussed in Chapters 3 and 5, with the outcomes emphasizing the importance of bridging accessibility gaps. Overall, both NMR and MMR increased with decreasing access metrics further emphasizing the importance of proximity to hospital care.

Policy makers can therefore use the results of the assessment to model scenarios of impact of improving accessibility. For example, in Kenya where the relationship used accessibility metricof verified CEmONC hospitals shows that achieving universal coverage of all births within 2 hours can reduce MMR in high burden counties of Mandera, Marsabit, Turkana and Wajir would reduce by 457, 452, 647 and 540 per 100,000 livebirths respectively. Similarly, Samburu, Turkana and West Pokot counties with access to VLBW quotients of less than 40, can reduce their NMRs by approximately 12 deaths per 1,000 livebirths by ensuring all births are within two hours of a VLBW hospital, further pushing the country towards achieving 2030 goals of 12 NMR by ensuring adequate access to quality VLBW hospitals. These numbers are important when decisions on prioritisation of health interventions are made and for the country to achieve the defined maternal and newborn mortality goals. As has been discussed earlier, strategies that ensure mothers arrive in hospitals in a timely manner in case of an emergency need to be adhered to.

However, analysis of the relationship had some limitations, most of which were discussed in the relevant discussion chapters. The main outcome of both sets of analysis was the need to improve data collection for both MMR and NMR [Boerma et al., 2018]. This includes collecting cause specific mortality estimates which can tease out those requiring hospital services. Both analyses were not able to extract mortality due to causes that require either CS or inpatient newborn care that were shown in Sections 1.6 and 4.2.8.

In Chapter 3, the GBD outcomes were used and these are often generated using sparse sources of information from household survey data but heavily relied on covariates to temporally project estimates to 2015. Maternal mortality is also rare, implying that its estimation from household surveys often produces wide confidence intervals, hence the over-reliance on modelling to produce credible estimates. The alternative would have been to use the estimates of neonatal and maternal mortality from the WHO [Alkema et al., 2016; UNIGME, 2018], but these use similar if not fewer datasets and comparisons have shown that they have wider confidence intervals in the outputs [Alkema & You, 2012; Kassebaum et al., 2014].

To improve understanding of MMR, countries have been encouraged to collect information on maternal mortality during the census collection exercises [Hill et al., 2001]. So far in SSA, seven countries – Ghana (2010), Kenya (2009), Senegal (2013), Tanzania (2012), Uganda (2014), Zambia (2010) and Zimbabwe (2012) have successfully collected subnational level data on maternal mortality during their most recent population censuses. The census was important in providing county level estimates of MMR and was used in the regression analysis. In addition to the census, the EQUIST tool- which relies on the distribution of intervention to produce sub-national level estimates was also used.

For neonatal mortality, the primary source of data is the DHS, which often has challenges in misreporting of dates of birth, misreporting of age at deaths and underreporting of deaths in some instances due to cultural barriers. The estimates are always prone to large sampling errors and given the sensitivity of NMR to quality of data, a high NMR may not necessarily mean improvement in newborn outcomes but may indicate better data collection [Mwale, 2004]. Similar challenges are also faced in the case of maternal mortality with the additional problem of being extremely rare meaning modelled estimates at subnational levels often have wide confidence intervals [Hill et al., 2018].

Ultimately, for accurate and timely monitoring of maternal and newborn deaths, countries will need to invest in improving their vital registration systems. Tied to improving data collection on outcomes, there is also need to improve our understanding of other factors that may have confounded the relationship. For example, cultural practices and beliefs can significantly impede access to facilities. Other factors that improve or reduce access may also result to residence such as urbanization and accounting for such require small scale studies.

## 6.7 What knowledge does this thesis add?

This thesis aimed to address the questions in Table 1.19 based on review of previous studies in Chapter 1. The importance and implications of this work have been provided in detail in each of the discussion sections of the analytical Chapters and are provided briefly here.

The first spatial census of hospitals in 48 SSA countries was undertaken, with the results made publicly available for further interrogation and updating by countries. The process demonstrated the use of multiple sources of data to develop master health facility lists in countries which lack such resources. This database was therefore used to interrogate, for the first time, geographic access to emergency hospital services. In the process of training the accessibility model, treatment seeking information was used and thus the outputs incorporated information on how patients are likely to use hospitals. This was also an opportunity to model accessibility at finer resolutions (100m) while previous studies have mostly used 1km spatial resolutions. In addition to defining geographic access to emergency hospitals, the database has been extended to mapping all health facilities [Maina et al., 2019], defining geographic access to all health facilities [Alegana et al., 2018], and mapping access to surgical care [Juran et al., 2018].

Using an example of Kenya and CS and VLBW services as tracers for CEmONC services, this work shows that the definition of what a hospital as provided in the HSSPs is inadequate, and definition requires service availability assessment. Less than half of what are termed hospitals in Kenya have the minimum criteria for provision of CEmONC service provision. The assembled CS and VLBW hospitals were also used to show how marginalization to these crucial hospital services is in Kenya for livebirths. The situation is likely to extend to other countries and other hospital services. Most importantly, as Oxygen was a useful component in defining VLBW hospitals, this work was extended to looking at Kenyas preparedness to care for SARS-CoV-2 patients [Barasa et al., 2020].

An understanding of the relationship between geographic access to hospital services and both maternal and neonatal mortality is provided, at continental levels and at sub national levels. The results of these models highlight, for the first time, the importance of improving geographic accessibility to hospitals in SSA. However, there are still several research questions that arise from this work.

## 6.8 Future research questions

First, the hospital list assembled had some gaps, with some sources outdated and this needs to be refined, to capture the complete picture of health facilities in SSA. This can only be done through strengthening the development of master facility lists in the countries or developing a feedback strategy, where countries assess and update the hospital database developed herein. In addition, there is need to adequately define what hospitals are based on availability of services and infrastructure in other LMICs given the inadequacy of current definitions of hospitals. This would essentially cover all the services envisioned in the HSSPs and require the use of service availability datasets. Alternatively, the methodology can also be used to assess ability of hospitals to provide other services such as surgery individually. Countries also need to invest in developing road network databases, with additional information such as road condition, and as has been shown in the Kenya level analysis, this is important in understanding accessibility.

Secondly, the accessibility model requires refinement using patient level data that incorporates additional complexities of transport such as waiting times. This study assumed catchment areas of 2 hours, but this may vary depending on coverage of facilities. Future studies should especially focus on using patient level attendance information to map catchment areas of CEmONC facilities as this would capture issues such as preferences. The availability of patient level data from DHIS 2 tracker module which captures residence of patients can be key but requires the addressed to be matched to village level spatial datasets. In addition, future accessibility models should account for factors such as competition between hospitals as some 'larger' hospitals tend to attract more patients compared to smaller hospitals. Thus future models should account for capacity of hospitals in defining geographic accessibility. Undertaking such accessibility analysis using higher resolution data would also improve the spatial accessibility models.

Models for estimating population distribution also need refinement. For refined accessibility metrics, there is need to improve our current understanding of where populations live at spatial resolutions higher than 100m for finer heterogeneity in access metrics. This would require the use of population metrics that use building footprints such as Facebook [Facebook Connectivity Lab & CIESIN, 2017]. In addition, there is need for improved understanding of the population in need of VLBW and CS services, by accounting for all the factors that have been shown to be risk factors. For example, placental malaria has been shown to be associated with increased probability of giving birth to a baby with LBW and accounting for such information would improve the understanding of births at risk.

Thirdly, individual level data can also be extended to exploring the influence of access and quality of care on mortality, and this can leverage on hospital level datasets. In addition, countries have been encouraged to collect information on maternal mortality from their vital registration systems and studies are needed to understand drivers of this outcome in each country. Lastly, the accessibility outcomes can be used in a spatial domain to develop referral zones and also test the impact of using other interventions such as ambulances and waiting homes to improve outcomes.

## Publications arising from this thesis.

**<u>Ouma PO</u>,** Maina JK, Thuranira PN, Macharia PM, Alegana VA, English M, Okiro EA, Snow RW (2018)**.** Access to emergency hospital care provided by the public sector in sub-Saharan Africa in 2015: a geocoded inventory and spatial analysis. *The Lancet Global Health*. **6.** e342–e350. [PMCID: PMC5809715] [PMID: 29396220]

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Maina J, **<u>Ouma PO</u>**, Macharia PM, Alegana VA, Mitto B, Fall IS, Noor AM, Snow RW, Okiro EA (2019). A spatial database of health facilities managed by the public health sector in sub Saharan Africa. *Scientific data.* **6.** 134. [PMCID: PMC6658526] [PMID: 31346183]

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### Other publications on marginalisation, hospital mapping and service availability

Barasa EW, **<u>Ouma PO</u>,** Okiro EA (2020). Assessing the Hospital Surge Capacity of the Kenyan Health System in the Face of the COVID-19 Pandemic**.** *Plos One.* **7.** e0236308. [PMCID: PMC7371160] [PMID: 32687538]

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**Published blogs**

**Ouma PO** & Okiro EA. People across Africa have to travel far to get to a hospital. We worked out how far, September 2018; https://theconversation.com/people-across-africa-have-to-travel-far-to-get-to-a-hospital-we-worked-out-how-far-102585

**Ouma PO** & Okiro EA. África: algunas soluciones para aminorar el largo camino al hospital, September 2018; https://theconversation.com/africa-algunas-soluciones-para-aminorar-el-largo-camino-al-hospital-103391

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# Appendices

**Appendix 1:** References for HSSPs and country level documents showing hospital numbers and service delivery structure.


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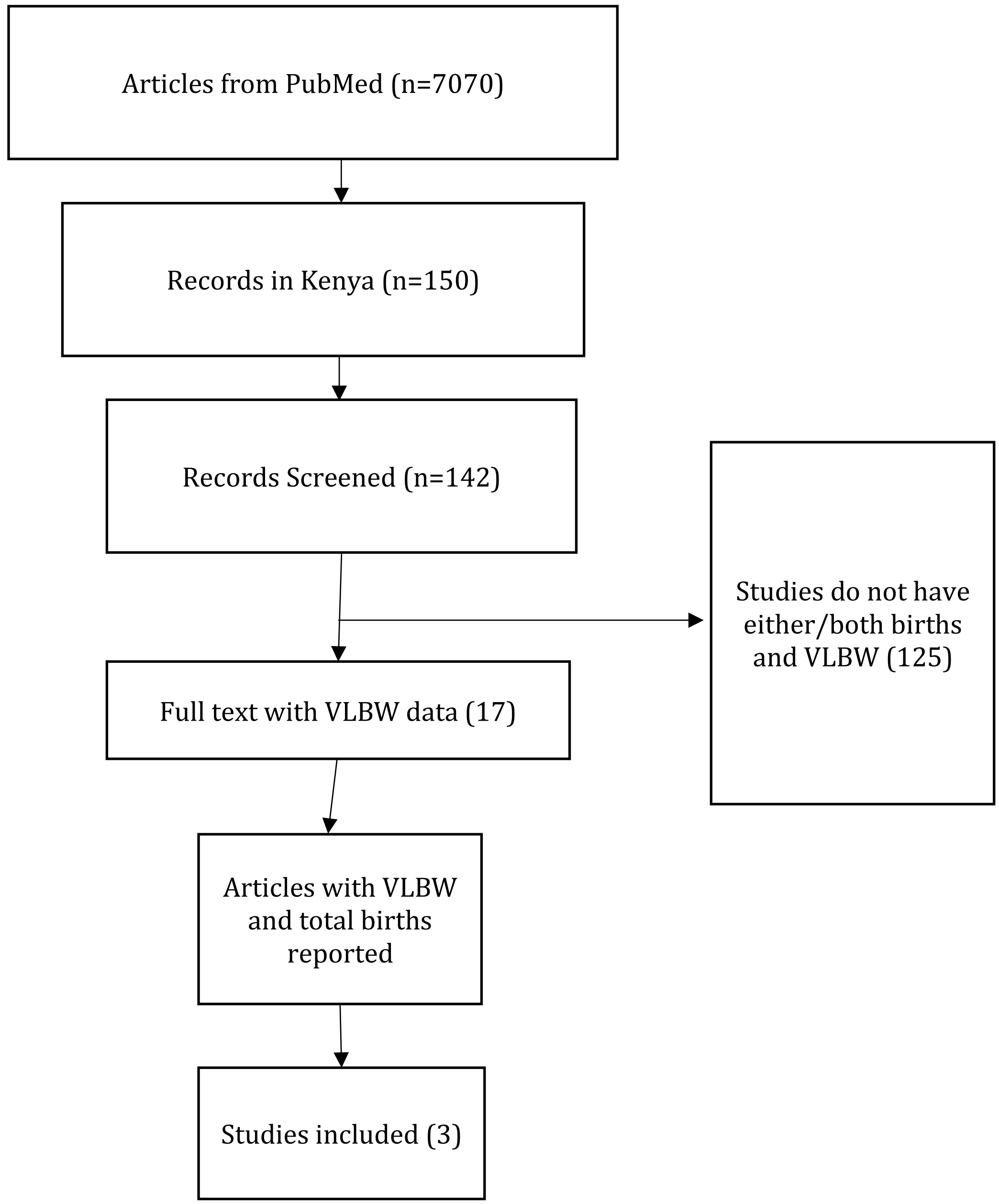
**Appendix 2:** Flow diagram for extracting articles estimation prevalence of VLBW.



**Appendix 3**: Characteristics of studies and data used to estimate the prevalence of very low birth weight in Kenya. The table shows information on the number of children with VLBW, the total number of livebirths and the year the data represents.

| Source | Year | Setting | VLBW % | Registry data/Card? | Total birth weights reported | Reported weight collected within 1 hour | Total births | Number VLBW (<1500g) |
|---|---|---|---|---|---|---|---|---|
| KHDSS | 2018 | KDSS | 1.53% | Y | Y | Y | 2,744 | 42 |
| [Mutua et al., 2015] | 2015 | NUDSS | 1.10% | Y | Y | Y | 4,389 | 48 |
| DHS | 2013 | Village | 0.80% | Y | Y | N | 4,184 | 334 |
| Were et al | 2009 | 3 hospitals | 1.90% | Y | N | N | 13,684 | 260 |
| Aluvaala et al | 2015 | 22 hospitals | 1.62% | Y | Y | N | 3,826 | 62 |
| Odhiambo et al | 2012 | 2 hospitals | 1.47% | Y | Y | N | 7,623 | 112 |
| CIN H1 | 2018, 1 month | 1 Hospital | 2.44% | Y | N | Y | 492 | 12 |
| CIN H2 | 2018, 9 months | 1 Hospital | 3.40% | Y | N | Y | 3,260 | 111 |
| CIN H3 | 2018, 9 months | 1 Hospital | 1.79% | Y | N | Y | 4,247 | 76 |
| CIN H4 | 2018, 1 month | 1 Hospital | 2.58% | Y | N | Y | 581 | 15 |
| CIN H5 | 2018, 9 months | 1 Hospital | 2.78% | Y | N | Y | 4,278 | 119 |
| CIN H6 | 2018, 9 months | 1 Hospital | 2.50% | Y | N | Y | 2,755 | 69 |
| CIN H7 | 2018, 1 month | 1 Hospital | 2.23% | Y | N | Y | 761 | 17 |
| CIN H8 | 2018, 9 months | 1 Hospital | 1.53% | Y | N | Y | 2,884 | 44 |
| CIN H9 | 2018, 9 months | 1 Hospital | 3.16% | Y | N | Y | 5,290 | 167 |
| CIN H10 | 2018, 9 months | 1 Hospital | 1.96% | Y | N | Y | 5,880 | 115 |
| CIN H11 | 2018, 9 months | 1 Hospital | 1.53% | Y | N | Y | 9,103 | 139 |
| CIN H12 | 2018, 9 months | 1 Hospital | 2.21% | Y | N | Y | 4,977 | 110 |
| CIN H13 | 2018, 9 months | 1 Hospital | 2.31% | Y | N | Y | 3,720 | 86 |
| CIN H14 | 2018, 12 months | 1 Hospital | 1.36% | Y | N | Y | 17,910 | 243 |
| CIN H15 | 2018, 1 month | 1 Hospital | 2.60% | Y | N | Y | 732 | 19 |
| CIN H16 | 2018, 9 months | 1 Hospital | 1.67% | Y | N | Y | 2,389 | 40 |
| KDH | 2018, 12 months | 1 Hospital | 1.81% | Y | Y | Y | 5,642 | 102 |

The CIN does not record information on the total number of births in the hospitals and this was extracted from the DHIS 2. The total number of births were extracted for each corresponding period where VLBW data was available. Data was also obtained from the Kilifi District Hospital (KDH) surveillance system through the KEMRI Wellcome Trust Data request portal. To check the accuracy of the DHIS 2 data, monthly livebirths data for the KDH was extracted from DHIS 2 and compared with what was provided by the surveillance system. Differences ranged from 2 to 43 for the 12 months in 2018 with a total livebirth being 5,642 from the DHIS 2 and 5,762 from the KDH surveillance system. For consistency, the DHIS 2 estimates were adopted. To calculate the proportion of livebirths in VLBW category, the weighted mean prevalence was calculated. The highest weights were assigned to studies/data sources which met all the three quality criteria like those used in the literature review. Those with only one quality criteria met had the lowest weights.

**Appendix 4** Roads classification in Kenya as per the transport act. A description of traffic expected to be channeled through each class is also provided.

| Road Class | Description |
|---|---|
| **NATIONAL TRUNK ROADS** | |
| S | Highways that connect two or more cities meant to carry a large volume of traffic using the safest legal speed of movement |
| A | Strategic routes and corridors that connect international boundaries at specific points of immigration and entry, including international terminals such as international airports and seaports. |
| B | Link national trading and economic hubs, county headquarters and other important national centres. They also provide connection to Class A roads |
| H | Urban major arterial highways meant to carry through traffic between distantly separated places in a city or municipality. They provide mobility within an urban area |
| J | Minor arterials that allow mobility between different zones of the urban area including the bus routes |
| **SECONDARY NATIONAL TRUNK ROADS** | |
| C | Regional routes that link county headquarters, important regional headquarters to each other and class A or Class B roads. |
| D | Link constituency headquarters, town centres and other municipal centres to each other and to higher class roads. |
| **COUNTY ROADS** | |
| E | Major feeder roads linking important constituency centres linking meant to carry local traffic and linking important constituency centres. |
| F | Minor feeder roads linking market centres to each other. Meant to carry and to channel traffic to the higher-class E roads. |
| G | Roads linking farms to markets and meant to carry farm produce and farm inputs traffic to and from the markets |
| K | Roads linking farms to markets and meant to carry farm produce and farm inputs traffic to and from the markets |
| L | Urban minor collector roads meant to perform a similar function as the class K roads i.e. to collect traffic from the local roads and channel to the arterial roads. |
| M | The main business and shopping streets in the urban areas meant to provide access to commercial properties and residential areas and cater for a high level of pedestrian traffic |
| R | The main business and shopping streets in the urban areas meant to provide access to commercial properties and residential areas and cater for a high level of pedestrian traffic. |
| T | Provide direct access to groups of residential properties. This is the lowest class of public roads and therefore Class P roads will provide all other public access (e.g. access to social amenities such as schools, hospitals, etc.) not provided by higher-class roads |

**Appendix 5:** Transport speeds used in creating the cost friction surface. For roads, only those in poor condition were deemed impassable in the wet period.

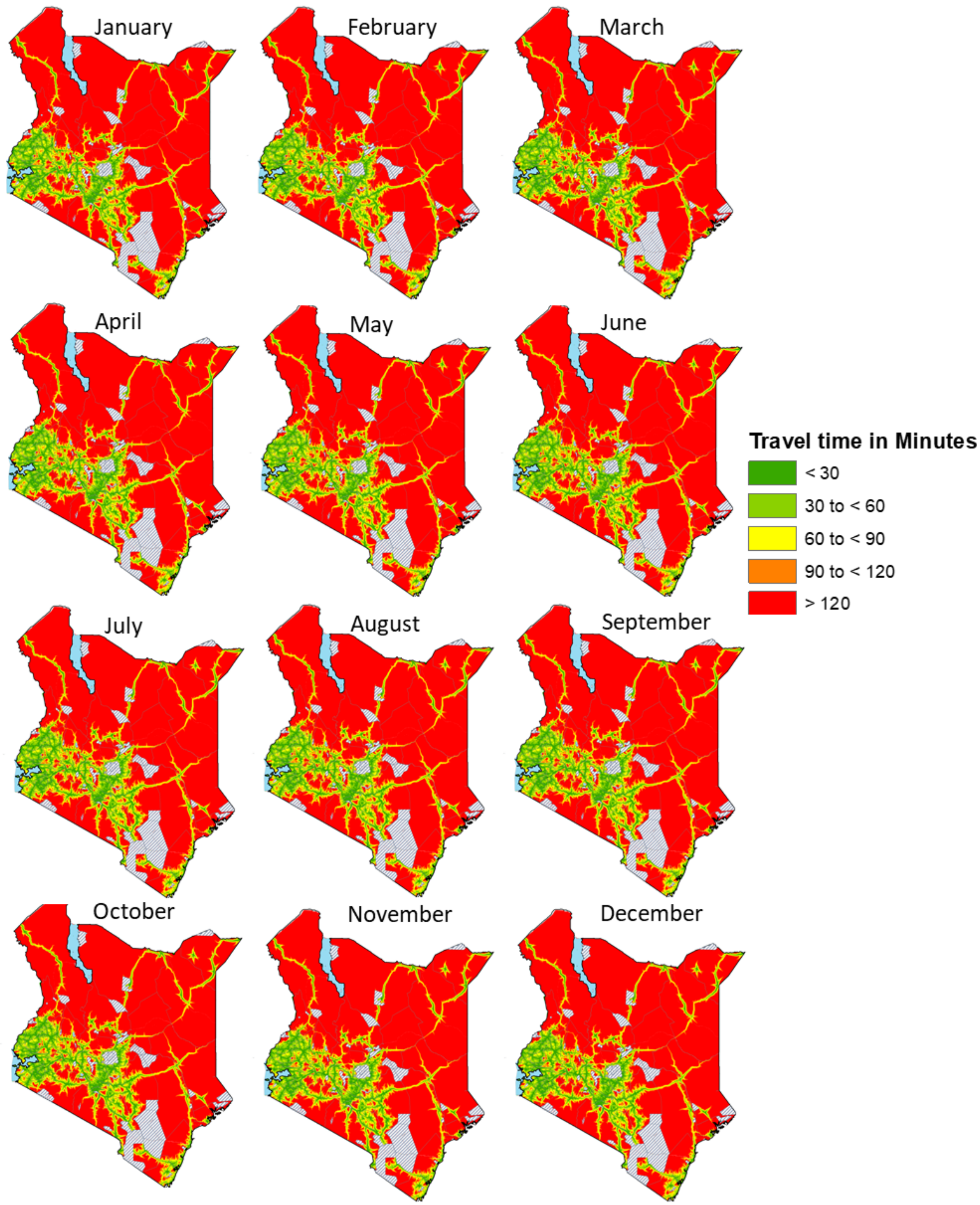
| Data | Classification | Speed (Km/hr.) -Dry | Model (Dry) |
|---|---|---|---|
| Land Use | Cultivated Land | 5 | Walking |
| | Tree cover | 5 | Walking |
| | Grassland | 5 | Walking |
| | Shrubland | 4 | Walking |
| | Wetland | 2 | Walking |
| | Urban Areas | 5 | Walking |
| | Water Bodies | 0 | Walking |
| | Forest | 0 | Walking |
| Roads | Class S | 110 | Driving |
| | Class A | 80 | Driving |
| | Class B | 60 | Driving |
| | Class H | 50 | Driving |
| | Class J | 50 | Driving |
| | Class C | 50 | Driving |
| | Class D | 40 | Driving |
| | Class E | 30 | Driving |
| | Class F | 30 | Driving |
| | Class G | 20 | Driving |
| | Class K | 20 | Driving |
| | Class L | 20 | Driving |
| | Class M | 15 | Driving |
| | Class R | 5 | Walking |
| | Class T | 5 | Walking |
| DEM | Slope | $W = 6 * \exp\{-3.5 * \text{abs}(S + 0.05)\}$ | Walking |

**Appendix 6**: County level number of hospitals by ownership category

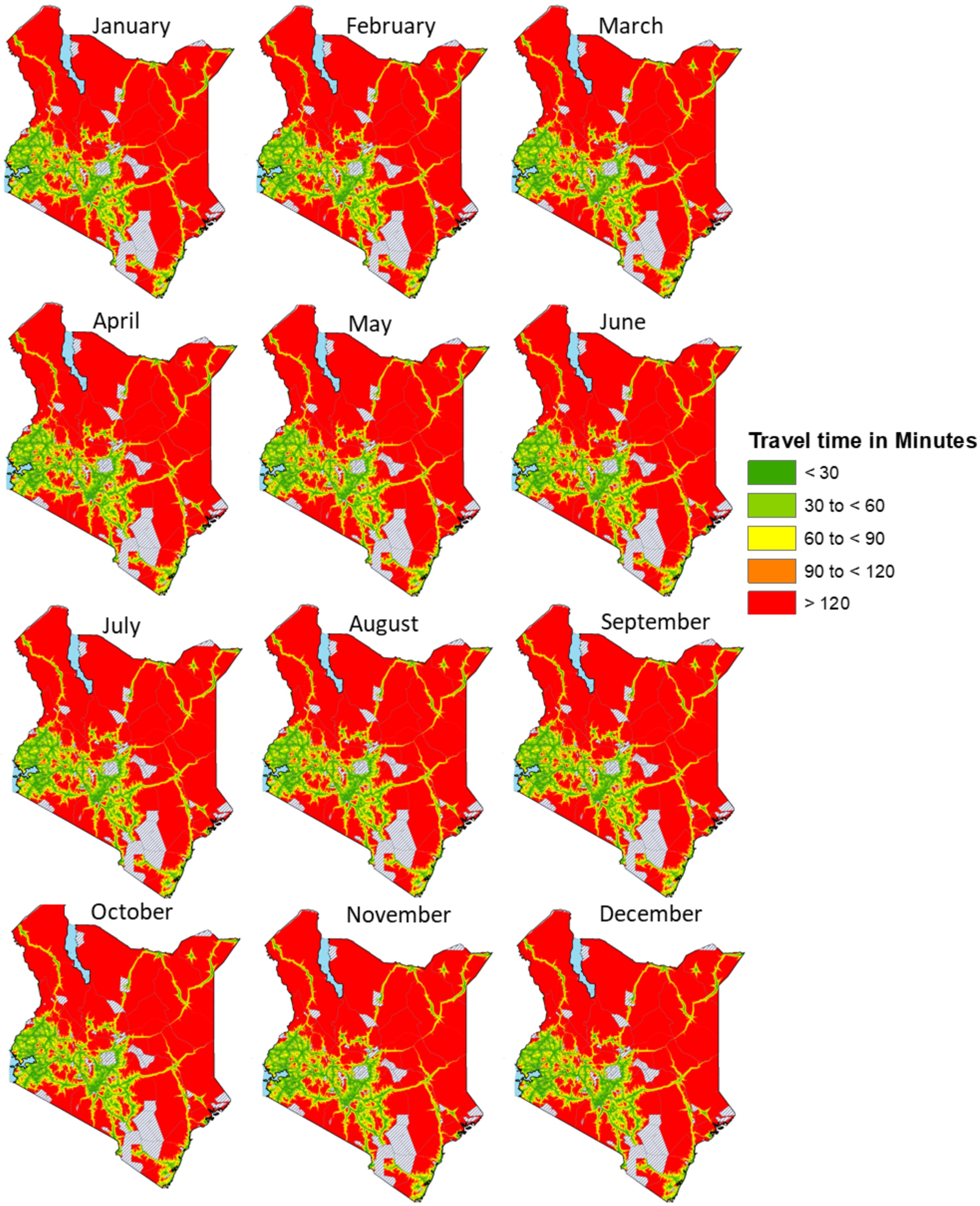
| County | FBO/NGO | | MoH | | Private | |
|---|---|---|---|---|---|---|
| | CS | VLBW | CS | VLBW | CS | VLBW |
| Baringo | 1 | | 2 | 2 | | |
| Bomet | 2 | 1 | 1 | 1 | | |
| Bungoma | 2 | 1 | 5 | 3 | 2 | 1 |
| Busia | 1 | 1 | 4 | 4 | | |
| Elgeyo_Marakwet | 1 | | 1 | 2 | | |
| Embu | 1 | | 4 | 1 | | |
| Garissa | | | 4 | 2 | | 1 |
| Homa_Bay | 1 | 1 | 4 | 4 | 1 | |
| Isiolo | | | 1 | 1 | | |
| Kajiado | 1 | | 3 | 3 | 2 | 1 |
| Kakamega | 2 | 1 | 4 | 5 | | |
| Kericho | 1 | 1 | 4 | 4 | 3 | 4 |
| Kiambu | 7 | 7 | 7 | 5 | 3 | 5 |
| Kilifi | 1 | 1 | 3 | 3 | 1 | 1 |
| Kirinyaga | 2 | 2 | 3 | 2 | | |
| Kisii | 2 | 2 | 5 | 3 | 6 | 3 |
| Kisumu | 3 | 3 | 3 | 4 | 7 | 5 |
| Kitui | 2 | 2 | 2 | 5 | 2 | |
| Kwale | | | 3 | 2 | | |
| Laikipia | 1 | | 2 | 1 | 3 | 2 |
| Lamu | | | 3 | 2 | | |
| Machakos | 1 | 1 | 3 | 4 | 3 | 1 |
| Makueni | | | 7 | 5 | | |
| Mandera | | | 4 | 3 | | |
| Marsabit | 1 | 1 | 3 | 2 | | |
| Meru | 6 | 4 | 4 | 5 | | |
| Migori | 1 | 1 | 2 | 1 | 6 | 2 |
| Mombasa | 4 | 2 | 4 | 2 | 7 | 5 |
| Muranga | 2 | 1 | 5 | 3 | 1 | |
| Nairobi | 4 | 3 | 5 | 5 | 15 | 14 |
| Nakuru | 2 | 1 | 5 | 4 | 8 | 6 |
| Nandi | 1 | 1 | 3 | 2 | 1 | |
| Narok | 1 | | 2 | 2 | 1 | 1 |
| Nyamira | | | 1 | 3 | | |
| Nyandarua | 1 | 1 | 2 | 1 | | |
| Nyeri | 3 | 3 | 4 | 4 | 2 | 1 |
| Samburu | 1 | 1 | 1 | 1 | | |
| Siaya | 1 | | 3 | 3 | 2 | 1 |
| Taita_Taveta | | | 3 | 3 | 1 | 1 |
| Tana_River | | | 2 | 1 | | |
| Tharaka_Nithi | 2 | 1 | 2 | 1 | | |
| Trans_Nzoia | 1 | 1 | 2 | 2 | 1 | |
| Turkana | 2 | | 2 | 2 | | |
| Uasin_Gishu | | | 1 | 2 | 5 | 3 |
| Vihiga | 1 | 1 | 1 | 1 | | |
| Wajir | | | 3 | 2 | | |
| West_Pokot | 1 | | 1 | 1 | | |
| **Total** | **67** | **46** | **143** | **124** | **83** | **58** |

## Appendix 7: Accessibility across different months for access to both tracer conditions

Monthly variation in travel time to the nearest CS hospital. Dark green areas are those within 30 minutes while red shows the areas more than two hours from the nearest CS hospital. The shaded regions are the protected areas, considered as barriers to travel



Monthly variation in travel time to the nearest VLBW hospital. Dark green areas are those within 30 minutes while red shows the areas more than two hours from the nearest VLBW hospital. The shaded regions are the protected areas



**Appendix 8**: County level median accessibility quotients of population within 2 hours of a confirmed, CS and VLBW hospital with minimum and maximum values in brackets.

| County | Confirmed Hospitals | Access to all CS | Access to all VLBW |
|---|---|---|---|
| Baringo | 53.55 [53.54 to 63.68] | 54.13 [54.12 to 64.87] | 56.75 [53.53 to 63.64] |
| Bomet | 90.61 [90.61 to 98.94] | 91.98 [91.98 to 99.02] | 91.91 [90.77 to 98.91] |
| Bungoma | 97.44 [97.44 to 99.45] | 97.93 [97.93 to 99.52] | 97.76 [97.51 to 99.45] |
| Busia | 98.53 [98.53 to 99.11] | 98.53 [98.53 to 99.11] | 98.59 [98.53 to 99.11] |
| Elgeyo Marakwet | 49.02 [48.94 to 67.49] | 68.14 [68.14 to 84.68] | 66.50 [61.83 to 78.54] |
| Embu | 94.56 [88.34 to 94.61] | 96.71 [91.40 to 96.71] | 91.86 [88.40 to 94.76] |
| Garissa | 37.08 [32.93 to 37.15] | 47.88 [42.79 to 47.95] | 35.87 [32.95 to 37.18] |
| Homa Bay | 90.99 [90.99 to 95.23] | 92.05 [92.05 to 95.58] | 92.24 [91.46 to 95.56] |
| Isiolo | 49.34 [45.62 to 49.35] | 50.50 [47.16 to 50.52] | 48.05 [45.78 to 49.46] |
| Kajiado | 64.29 [55.27 to 64.83] | 64.37 [55.45 to 64.94] | 60.72 [55.24 to 64.80] |
| Kakamega | 98.89 [98.89 to 99.21] | 99.07 [99.07 to 99.21] | 99.02 [98.99 to 99.21] |
| Kericho | 94.34 [94.34 to 98.16] | 94.49 [94.49 to 98.30] | 94.75 [94.37 to 98.14] |
| Kiambu | 99.76 [99.53 to 99.83] | 99.76 [99.53 to 99.83] | 99.69 [99.53 to 99.83] |
| Kilifi | 84.89 [77.31 to 85.21] | 84.90 [77.36 to 85.21] | 81.81 [77.31 to 85.21] |
| Kirinyaga | 98.68 [98.64 to 98.68] | 98.68 [98.67 to 98.68] | 98.66 [98.64 to 98.68] |
| Kisii | 99.92 [99.92 to 100] | 99.95 [99.95 to 100] | 99.95 [99.94 to 100] |
| Kisumu | 99.34 [99.34 to 99.77] | 99.51 [99.51 to 99.80] | 99.51 [99.48 to 99.78] |
| Kitui | 70.71 [58.92 to 70.73] | 71.84 [59.46 to 71.86] | 67.84 [60.70 to 72.25] |
| Kwale | 90.19 [76.66 to 90.32] | 90.70 [78.46 to 90.83] | 84.54 [76.67 to 90.32] |
| Laikipia | 70.49 [64.46 to 79.48] | 71.13 [65.20 to 79.95] | 71.52 [64.46 to 79.47] |
| Lamu | 61.82 [55.30 to 62.12] | 70.22 [63.10 to 70.52] | 59.85 [55.30 to 62.12] |
| Machakos | 94.08 [84.68 to 94.26] | 94.21 [85.70 to 94.38] | 93.54 [88.55 to 96.13] |
| Makueni | 89.01 [78.38 to 89.06] | 89.54 [80.65 to 89.58] | 85.32 [78.48 to 89.10] |
| Mandera | 39.49 [34.56 to 39.49] | 41.86 [36.66 to 41.86] | 38.04 [34.56 to 39.49] |
| Marsabit | 40.89 [36.94 to 41.30] | 41.99 [37.71 to 42.40] | 39.80 [36.95 to 41.31] |
| Meru | 96.81 [93.32 to 96.81] | 97.03 [93.92 to 97.03] | 95.22 [93.32 to 96.81] |
| Migori | 82.33 [82.07 to 89.57] | 84.58 [84.33 to 92.46] | 83.88 [82.06 to 89.56] |
| Mombasa | 98.44 [98.21 to 98.53] | 98.45 [98.33 to 98.55] | 98.37 [98.21 to 98.53] |
| Muranga | 98.69 [96.16 to 99.55] | 99.38 [98.56 to 99.65] | 97.99 [96.72 to 99.63] |
| Nairobi | 99.79 [99.78 to 99.79] | 99.79 [99.78 to 99.79] | 99.79 [99.78 to 99.79] |
| Nakuru | 87.23 [84.37 to 93.98] | 88.50 [86.02 to 94.53] | 88.17 [85.09 to 94.02] |
| Nandi | 80.60 [80.60 to 96.90] | 86.55 [86.55 to 98.52] | 82.24 [80.60 to 96.84] |
| Narok | 45.07 [40.79 to 58.85] | 46.57 [42.28 to 60.61] | 45.88 [41.18 to 59.35] |
| Nyamira | 99.88 [99.88 to 99.99] | 99.99 [99.99 to 99.99] | 99.99 [99.99 to 99.99] |
| Nyandarua | 93.33 [88.66 to 97.57] | 93.62 [89.03 to 97.63] | 92.80 [88.87 to 97.57] |
| Nyeri | 96.18 [94.47 to 96.72] | 96.19 [94.63 to 96.73] | 95.63 [94.54 to 96.73] |
| Samburu | 37.19 [30.41 to 40.22] | 37.19 [30.41 to 40.22] | 35.86 [30.41 to 40.22] |
| Siaya | 94.28 [94.28 to 97.72] | 94.28 [94.28 to 97.73] | 94.60 [94.29 to 97.51] |
| Taita Taveta | 87.18 [76.03 to 87.30] | 87.18 [76.03 to 87.30] | 83.32 [77.63 to 88.48] |
| Tana River | 51.09 [36.95 to 51.61] | 51.38 [39.76 to 51.88] | 44.26 [36.58 to 51.35] |
| Tharaka Nithi | 79.72 [69.58 to 79.75] | 96.45 [87.85 to 96.45] | 74.54 [69.58 to 79.75] |
| Trans Nzoia | 94.38 [94.38 to 98.52] | 94.38 [94.38 to 98.52] | 96.15 [95.42 to 98.58] |
| Turkana | 22.61 [18.32 to 23.62] | 25.70 [22.16 to 26.54] | 21.76 [18.31 to 23.62] |
| Uasin Gishu | 96.19 [96.19 to 99.25] | 96.32 [96.28 to 99.46] | 98.81 [98.58 to 99.59] |
| Vihiga | 100 [100 to 100] | 100 [100 to 100] | 100 [100 to 100] |
| Wajir | 32.83 [26.63 to 32.89] | 34.67 [28.92 to 34.74] | 31.13 [26.63 to 32.89] |
| West Pokot | 32.57 [31.34 to 40.37] | 40.55 [39.06 to 49.46] | 34.44 [31.35 to 40.40] |
| **Total** | **80.81 [77.57 to 83.35]** | **82.24 [79.17 to 84.63]** | **80.45 [78.03 to 83.53]** |

**Appendix 9** County level median population within 1 hour of a VLBW and CS hospital with minimum and maximum values in brackets. The 2-hour access is also shown for comparison.

| County | Access to CS | | Access VLBW | |
|---|---|---|---|---|
| | 1 hour | 2 hours | 1 hour | 2 hours |
| Baringo | 22.80 | 54.13 | 22.80 | 56.75 |
| Bomet | 48.77 | 91.98 | 44.11 | 91.91 |
| Bungoma | 71.67 | 97.93 | 59.3 | 97.76 |
| Busia | 65.44 | 98.53 | 69.29 | 98.59 |
| Elgeyo Marakwet | 23.46 | 68.14 | 20.51 | 66.50 |
| Embu | 56.84 | 96.71 | 25.97 | 91.86 |
| Garissa | 46.04 | 47.88 | 21.07 | 35.87 |
| Homa Bay | 60.59 | 92.05 | 54.82 | 92.24 |
| Isiolo | 39.48 | 50.50 | 37.81 | 48.05 |
| Kajiado | 48.59 | 64.37 | 43.62 | 60.72 |
| Kakamega | 64.84 | 99.07 | 57.63 | 99.02 |
| Kericho | 67.10 | 94.49 | 67.38 | 94.75 |
| Kiambu | 78.28 | 99.76 | 76.39 | 99.69 |
| Kilifi | 36.19 | 84.90 | 33.59 | 81.81 |
| Kirinyaga | 79.48 | 98.68 | 68.69 | 98.66 |
| Kisii | 86.32 | 99.95 | 85.92 | 99.95 |
| Kisumu | 73.07 | 99.51 | 73.48 | 99.51 |
| Kitui | 28.90 | 71.84 | 33.15 | 67.84 |
| Kwale | 27.04 | 90.70 | 17.16 | 84.54 |
| Laikipia | 29.67 | 71.13 | 28.35 | 71.52 |
| Lamu | 57.41 | 70.22 | 51.36 | 59.85 |
| Machakos | 43.67 | 94.21 | 43.78 | 93.54 |
| Makueni | 37.97 | 89.54 | 30.23 | 85.32 |
| Mandera | 31.37 | 41.86 | 25.40 | 38.04 |
| Marsabit | 28.45 | 41.99 | 27.13 | 39.80 |
| Meru | 66.64 | 97.03 | 65.99 | 95.22 |
| Migori | 42.31 | 84.58 | 35.63 | 83.88 |
| Mombasa | 94.25 | 98.45 | 46.22 | 98.37 |
| Muranga | 77.18 | 99.38 | 59.64 | 97.99 |
| Nairobi | 99.67 | 99.79 | 99.64 | 99.79 |
| Nakuru | 58.00 | 88.50 | 53.17 | 88.17 |
| Nandi | 45.02 | 86.55 | 39.55 | 82.24 |
| Narok | 21.93 | 46.57 | 20.18 | 45.88 |
| Nyamira | 78.31 | 99.99 | 88.15 | 99.99 |
| Nyandarua | 32.89 | 93.62 | 30.47 | 92.80 |
| Nyeri | 62.56 | 96.19 | 67.19 | 95.63 |
| Samburu | 23.98 | 37.19 | 23.98 | 35.86 |
| Siaya | 51.23 | 94.28 | 50.97 | 94.60 |
| Taita Taveta | 46.84 | 87.18 | 48.61 | 83.32 |
| Tana River | 17.22 | 51.38 | 14.82 | 44.26 |
| Tharaka Nithi | 56.78 | 96.45 | 42.87 | 74.54 |
| Trans Nzoia | 55.53 | 94.38 | 56.27 | 96.15 |
| Turkana | 24.12 | 25.70 | 6.34 | 21.76 |
| Uasin Gishu | 48.96 | 96.32 | 57.62 | 98.81 |
| Vihiga | 95.20 | 100.0 | 94.87 | 100.0 |
| Wajir | 24.78 | 34.67 | 20.03 | 31.13 |
| West Pokot | 22.01 | 40.55 | 10.65 | 34.44 |

**Appendix 10:** Multivariable model results between 1-hour access quotients and both maternal and neonatal mortality.

| Variable | $NMR_{EQUIST}$ | |
|---|---|---|
| | **Coefficient** | **p value** |
| Intercept | 22.211 [-0.434 to 0.564] | 0.022 |
| Geographic access to hospitals (1 hour) | -0.151 [-0.327 to 0.024] | 0.050 |
| Wealth | -16.121 [-49.925 to 17.684] | 0.397 |
| Hworkforce | 0.079 [-0.512 to 0.669] | 0.824 |
| Meducation | 34.825 [7.608 to 62.042] | 0.263 |
| Fertility_Rate | 0.065 [-0.434 to 0.564] | 0.937 |

| Variable | $MMR_{Census}$ | | $MMR_{EQUIST}$ | |
|---|---|---|---|---|
| | **Coefficient [95% CI]** | **p value** | **Coefficient** | **p value** |
| Intercept | 265.586 [-871.319 to 1402.491] | 0.650 | 28.308 [3.592 to 53.024] | 0.030 |
| Geographic access to hospitals (1 hour) | -1.532 [-9.405 to 6.340] | 0.705 | -0.181 [-0.368 to 0.005] | 0.064 |
| Wealth | 92.892 [-1281.042 to 1466.826] | 0.895 | -24.261 [-59.299 to 10.778] | 0.182 |
| Hworkforce | -6.621 [-31.450 to 18.207] | 0.604 | 0.013 [-0.566 to 0.593] | 0.964 |
| Meducation | 1149.285 [68.498 to 2230.071] | 0.044 | 38.856 [13.072 to 64.639] | 0.005 |
| Fertility_Rate | 15.687 [-188.716 to 220.090] | 0.881 | 0.025 [-0.470 to 0.521] | 0.921 |
| Birth_Interval | 1715.670 [-1209.214 to 4640.554] | 0.257 | | |
| Adolescent_Fertility | -30.853 [-52.078 to -9.628] | 0.007 | | |